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EFFECTIVENESS OF PRESCRIBED FIRE ON MEETING FUEL LOAD AND WILDLIFE HABITAT MANAGEMENT OBJECTIVES IN EAST TEXAS NATIONAL FORESTS

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By

TREY WALL, Bachelor of Science in Forestry

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ABSTRACT

Using standardized methodology outlined by the United States Forest Service and the National Forests and Grasslands in Texas' Fire Monitoring Program for data collection, the efficacy of current Forest Service prescribed burn regimes were analyzed for 24 study sites in East Texas National Forests. Study sites were located within Sam Houston, Davy Crockett, and Angelina/Sabine National Forests. Efficacy was determined by comparing defined management objectives established by the Forest Service to the data collected at the study sites. The results conclude that most objectives, as outlined by the Forest Service, are not being met with the current practices. Re-visitation of monitoring type definitions and objectives may be necessary, as well as a reduction in forest overstory tree basal area, initiation of more growing season burns, creating mosaics of burn intervals and ignition patterns, and herbicide applications to more effectively restore the forests to native, historical levels.

Because Texas Parks and Wildlife Department has wildlife management areas within the National Forests, the prescribed burn data was also used to investigate a direct relationship between white-tailed deer and prescribed fire years. The resulting analysis displays a peak in body weight and various antler measurements two-years post fire. Antler beam and inside spread measurements were confirmed to show statistical significance. The results indicate a beneficial relationship between deer and frequent prescribed fire.

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INTRODUCTION

Fire plays a vital role in establishing, maintaining, and enhancing the health and quality of many forested ecosystems. Management objectives such as restoring forests, creating and maintaining natural successional regimes, and eradication or suppression of invasive plant and animal species can be met with the supplementation of prescribed fire to other silvicultural and harvesting practices. Texas National Forests are culturally and economically important, providing thousands of jobs and billions of dollars of wages annually. Texas itself is one of the top 10 timber producing states in the U.S. (Maxwell, 2010). The Piney Woods region in eastern Texas has also been labeled as one of the most endangered ecoregions in the United States, where only three percent of its remaining habitat is considered "intact" (Weakley *et al.*, n.d.), on top of being host to multiple endangered plant and animal species. Evaluating the efficacy of management practices is imperative in understanding associated ecological responses in order to adapt silvicultural methods to more effectively restore and conserve threatened ecosystems.

Prescribed fire supports the reduction of future wildfire potential, synthesizes and recycles nutrients for vegetative growth, maintains open, park-like stand structure, and reduces potentially detrimental vegetative encroachment, such as some hardwoods and invasive species (Carey, 1992). Varying types of fire regimes through history have shaped many North American ecosystems. Where fire is removed or suppressed in fire-adapted environments, forested areas may shift to monocultures characterized by excessive fuel loads, overstocking (Sparks *et al*, 1998), and inadequate production, which in turn provides an opening for diseases and damaging insects (Wright & Bailey, 1982). National forests are not only culturally and economically important, but also provide wildlife habitat, protect wetlands and watersheds, and are a major economic driver (timber and anthropogenic recreation).

Unlike designated wilderness areas, National Forests and Grasslands in Texas (NFGT) require vigorous field monitoring techniques, data collection, and silvicultural implementations to effectively and safely manage resources for multiple uses, sustained harvests, protection and habitat perpetuity. The United States Forest Service (USFS) aims to restore the use of prescribed fire, improve fire regimes across all forests, increase agency knowledge of fire effects, and link prescribed fire implementations to burn objectives to define and accurately achieve various and ever-evolving management goals. The USFS further aims to sustain the diversity, health, and productivity of the forests to meet the needs of present and future generations (United States Department of Agriculture, n.d.).

This study analyzed current NFGT prescribed fire rotations and management practices to assess their impacts and provide insight into future habitat restoration efforts. It also attempted to identify if current burn prescriptions are accurately and efficiently meeting assorted management goals. Habitat restoration, protection and perpetuation of native, natural ecosystems is becoming increasingly important. This research examined current methods to provide potentially needed recommendations in order to more adequately and effectively manage ecosystems that are culturally, economically, ecologically, and aesthetically valuable, whereby small mistakes or misguided management activities can have devastating and long-lasting effects.

The USFS and, by extension, the NFGT, has adopted a standardized approach to fire monitoring based on the National Park Service's (NPS) "Fire Monitoring Handbook (FMH)" (USDI NPS, 2003). This approach was developed in 2003 to outline a minimum monitoring standard as well as facilitate uniform data collection associated with prescribed fire. The FMH is used in conjunction with the USFS' proprietary field methodology due in part to its scientifically defensible methods, plot sizes and shapes that are already commonly used, as well as the ease of using practiced protocols instead of "reinventing the wheel." Prior to the adoption of this method, the Forest Service did not have a standardized and quantitative approach for collecting data on the effects of fire.

The monitoring plan outlines collection of data from the understory to overstory, as well as soil and downed woody debris and fuel elements. This data allows researchers to physically analyze and statistically quantify fuel loads and vegetation types in the United States National Forests and subsequently aids in establishing and meeting both short and long-term management objectives. Management objectives can vary in each National Forest depending on forest cover type, target goals, timelines, and personnel. The FMH and associated field measurements can be implemented in essentially any forest type to meet varying degrees of research needs and management objectives.

As a secondary goal, this research involved examining fire management in Wildlife Management Areas (WMA) associated with the National Forest fire monitoring study sites. National Forests are important sources of recreation and hunting opportunities along with substantive economic and ecological benefits (Holsworth, 1973). The analysis attempted to identify if a relationship exists between prescribed burn history and white-tailed deer (*Odocoileus virginianus*) bodyweight and condition. These relationships could help provide state and government agencies guidance into future management practices in order to potentially maximize deer and ecosystem health, as well as increased hunting opportunities for the public.

Utilizing permanently installed plots based on the standardized methodology from the FMH and USFS Fire Monitoring Plan to collect field data, this project assessed previously collected fire monitoring information, collected new and ongoing data, assessed fire effects on white-tailed deer in WMA's, and recommends alterations or improvements to the current fire regimes used by the USFS in Texas National Forests. Through detailed analysis of field measurements, the identification of these variables and trends can be used to further enhance and more efficiently meet current management goals in order to more effectively restore degraded and ecologically valuable ecosystems.

RESEARCH GOALS AND OBJECTIVES

Goals

The goals of this research included utilizing permanently installed fire monitoring plots across multiple compartments, districts, and cover types in East Texas National Forests. Ongoing data were collected as well as an interpretation of previously collected records in order to gain insights into the ecological effects and trends pertaining to controlled burns within Angelina, Sabine, Davy Crockett, and Sam Houston National Forests to determine the benefits and/or detriments of current burn regimes conducted by the USFS.

A secondary research goal was to analyze prescribed fire history in Bannister, Moore Plantation, Alabama Creek, and Sam Houston National Forest WMA's to investigate the ecological and physiological impacts, if any, on white-tailed deer body weight, condition, and abundance. The Texas Parks and Wildlife Department (TPWD) provided previously collected white-tailed deer data in relation to USFS burn practices. It is known that prescribed fires increase potential browse and mast availability for deer (Masters *et al.*, 1993), which would therefore enhance deer condition and landscape abundance, but a direct correlation between fire history and overall deer condition and abundance has not been identified.

Objectives

The specific objectives of this study were to:

1. Evaluate vegetation and habitat pre and post-burn in Texas National Forests.

2. Analyze current prescribed fire regimes and associated vegetation data in regards to meeting stated USFS management objectives.

3. Assess impacts of current burn regime on NFGT habitat as well as white-tailed deer body weight and antler condition.

LITERATURE REVIEW

Prescribed Burning in North America

Fire played an integral role in perpetuating and shaping healthy pine-grassland ecosystems in the southeastern United States (Buckner, 1989). Accounts of these ecosystems prior to European settlement have often been labeled as "open, parklike stands," characterized by a distinct grass-dominated understory and recurrent woody layer, which were heavily dependent on fire for continued propagation. The fuels in the understory and herbaceous layers were enough to carry frequent, low-severity fires through systems commonly ignited by Native Americans or by lightning strikes. After settlement, human activity heavily influenced the historical ecosystem processes, changing or wholly excluding fire intervals, fragmenting the landscape and deforesting many areas.

With the decline of frequent fire intervals came the encroachment of significantly denser forested landscapes (Sparks *et al.,* 1998). This increase in forest basal area and stand homogenization caused a decrease in available sunlight to the forest floor, reducing herbaceous plant growth and production which is important for many wildlife species (Sparks *et al.,* 1998; Ryan *et al.,* 2013). The endangered red-cockaded woodpecker (RCW) (*Picoides borealis*) and the Louisiana pine snake (*Pituophis ruthveni*), are examples of species whose decline can be almost singularly attributed to these increases in overstory and midstory densities. Additionally, evidence exists that fire exclusion is linked to a decline in butterfly diversities (Huntzinger, 2003). Further detrimental effects of fire exclusion include vastly altered fuels and associated fire behavior, as well as the deterioration of numerous ecosystem processes (Ryan *et al.*, 2013).

In 1910, Chief Forester Henry Graves of the USFS proposed that fire prevention and suppression was the "fundamental obligation" of the agency (Carle, 2002). This idea was contrary to the belief of his predecessor Gifford Pinchot who, along with President Theodore Roosevelt, advocated and understood the necessity of prescribed fire in many American ecosystems. In 1910, a massive wildfire in Montana and Idaho burned over three million acres and killed almost 100 people (Carle, 2002). This event in the northern Rocky Mountains, not to mention the propagandistic "Smokey Bear" campaign, further solidified the official stance against prescribed fires and institutionally entrenched the anti-fire beliefs into the American people. However, due in large part to the years of research conducted by Dr. Harold Biswell, these ideas eventually were overthrown in favor of slow reintegration of prescribed and "let burn" fires back into fire adapted ecosystems (Carle, 2002). In the late 1970's, the USFS adopted a "total fire management" policy which slowly increased the area burned through the years (Carle, 2002).

In forested ecosystems over time, fuel in the form of dead leaves, pine needles, and various types of woody and plant debris accumulate on the forest floor. This accumulation of fuel leaves open the opportunity for higher intensity burns, as well as an increased wildfire risk. When normal and historic prescribed fire intervals are maintained, this accumulation of fuel is kept to a minimum, manageable level, which reduces the chances of intense and potentially tragic wildfires. Due in large part to decades of fire suppression and subsequent fuel accumulation in American forests, an event similar to the 1910 wildfire occurred in 2000, as wildfires destroyed hundreds of homes in Los Alamos, New Mexico (Carle, 2002). After these fires, many questions arose, and subsequently, perceptions were altered which eventually shaped the protocols and methods employed by the USFS as well as many other institutions around the world today.

Prescribed fire, once perceived as a "great evil," was now making its way to the forefront of forest management and ecosystem restoration. Currently, natural resource agencies, such as the United States Department of Interior (USDI) and Agriculture (USDA), United States Fish and Wildlife Service (USFWS), USFS, the Bureau of Land Management (BLM), and Natural Resource Conservation Service (NRCS), recognize prescribed fire as a viable and vital habitat restoration tool to reduce fuel hazards, improve the health of natural ecosystems, remove invasive species, and maintain wildlife populations where fire is necessary for the species' continued survival (Tunnel, 2005).

Sociopolitical Issues and Constraints

Although the reintegration of fire as a management tool is scientifically validated, sociopolitical constraints remain as large hurdles. The re-introduction of fire into altered and fire-suppressed communities poses major risks for ecosystems and human settlements and structures (Ryan *et al.*, 2003). Where there were historically low-severity, frequent fires, many altered ecosystems with decades of fuel accumulation and plant compositional shifts now harbor an increased probability of high-severity, damaging conflagrations. Lastly, where North America was once dominated by large expanses of wilderness and containing only small islands of civilization, modern anthropogenic growth and expansion has pushed infrastructure and development to intermingle with natural landscapes and ecosystems, further expounding the risk of wildfire to persons and property. This intermingling is commonly referred to as the wildland-urban interface.

Currently, federal agencies on public lands adhere to the National Fire Plan (NFP), established by the United States Government in 2000. This $6 billion strategy is one of the largest ecosystem restoration initiatives in the world, encompassing fuel reductions on approximately 11 million acres (Nelson & Schoennagel, 2010). The plan attempts to reduce fuel hazards for both people and the environment, and restore historical productivity and ecosystem health to grasslands and forests by expanding prescribed fire as a management activity and tool (Tunnel, 2005). However, comprehensive evaluations of which forests are actually in need of "restoration" have not been attempted. Critics of the NFP state that the federal definition of "ecosystem restoration" is narrow, simply involving the removal of accumulated fuels in areas once characterized by low-severity, frequent fires. These areas have since been altered in one way or another by fire suppression or the introduction of cattle and other grazing animals, potentially rendering the federal definition of restoration and its associated management practices insufficient to adequately meet idealized goals (Nelson & Schoennagel, 2010).

Sociopolitical challenges may be ever-present, but oftentimes political, operational, and bureaucratic loopholes are far more difficult to conquer (Ryan *et al.,* 2013). All aspects of prescribed fire must be conducted within the confines of various laws and legislation such as the Clean Air Act (1963), Clean Water Act (1972), and Endangered Species Act (ESA) (1973). Ryan *et al.* (2013) presents the case that although the Clean Air Act was successful in reducing particulate emissions, it posed challenges to prescribed burning since smoke and particulates is an omnipresent reality of fire. Furthermore, with decades of fire suppression, the public simply is not accustomed to the smoke that accompanies landscape-burning.

Adequate scientific management may occasionally need to be exercised outside of the framework of existing litigation and laws. The ESA requires managers to consider the risks of prescribed burning to RCW populations, but does not take into consideration long-term effects of *inaction,* one of the very reasons RCW populations are currently endangered (Ryan *et al.,* 2013). Another example of governmental impediment is displayed in a study showing that the California USFS's most dominant goal was the reduction of wildfire hazards; ecosystem restoration (wildlife enhancement) and cultural resources were secondary (moderate) in importance ratings (Quinn-Davidson & Varner, 2012).

Ecology, Silvics, and Management

This research focused on three mixed-pine cover types within the research areas in east Texas. These cover types are dominated by three pine species: shortleaf pine (*Pinus echinata*), longleaf pine (*Pinus palustris*), and loblolly pine (*Pinus taeda*).

<u>Shortleaf Pine</u>

Shortleaf pine is one of the most commercially important conifers in North America, as well as having the largest range of any other pine in the southern United States, encompassing over 22 states (Lawson, 1990). It is shade intolerant and typically grows in humid environments, but retains more adaptability to varying conditions than other pine species. Annual precipitation averages 40 inches in the western portions and 60 inches at the southernmost tip, and ample cone crops are produced every three to six years (Lawson, 1990). Typically, shortleaf pine is found on the Ultisol soil order, and suborder Udults. Shortleaf pine also exhibits a unique seedling characteristic consisting of a j-shaped crook at ground level. These crooks persist for approximately 10 years and contain fire-adapted buds that sprout if part of the tree is killed above ground (Baker *et al.*, 1996).

Although fire tolerant, and noting the species' adaptability to varying conditions, shortleaf pine can also survive extended periods of fire suppression while still responding to release (Baker *et al.*, 1996). However, neglected shortleaf stands eventually become dominated with southern hardwood encroachment (Baker *et al.*, 1996) as seen in many forested areas (Figure 1). For timber production and promotion of an herbaceous understory, uneven-aged management that includes enlargement of regeneration gaps and removal of residual overstory trees in gaps should promote successful stand persistence (Baker *et al.*, 1996).

Figure 1. A shortleaf pine ecosystem showing encroachment of various hardwood species in Sabine National Forest, Texas 2018 (Photo by Wall, 2018).

In 1904, shortleaf pine encompassed approximately 30,000 square miles in eastern Texas, the most extensive forest type in the state (Bray, 1904), and also included post oaks, hickories, oaks, and sweetgums. Bray further noted that "...north of the Sabine River, from Longview through Cass and Bowie counties, the shortleaf pine forms compact forests over many hundreds of square miles," and at the time of publishing the Bureau of Forestry Publication No. 47, most of this had already been cut (Bray, 1904). Within these pine forests, where logging had begun sooner than loblolly and shortleaf due to the expansion of railroads in the late 1800's, most of the optimal timber had been cut by 1904 and taken over by thickets of oak (Bray, 1904). As the oil boom commenced, countless immigrants began to occupy the areas, in which many forests were cutover or killed to make room for cotton fields and sugar cane plantations.

Currently, shortleaf pine forests comprise less than 10% of their historic acreage (Anderson *et al.*, 2016). Upon arriving in North America, settlers were greeted by vast tracts of open pine woodlands. These trees provided sturdy, straight timber with which to build homes and boats. As the popularity and demand for shortleaf increased, settlers followed the tracts west through the southern states and into Texas. After 200 years of intense harvesting combined with decades of fire suppression, shortleaf pine ecosystems now stand as a shadow of their former glory (Anderson *et al.*, 2016). With the decline of shortleaf ecosystems, associated declines of many wildlife species followed, including the red-cockaded woodpecker, northern bobwhite (*Colinus virginianus*), numerous butterfly species, as well as one of the most rapidly declining bird species in North America - the endangered Bachman's sparrow (*Peucaea aestivalis*) (Anderson *et al.*, 2016).

Besides culturally and ecologically significant plant and animal losses, the margin for economic losses of shortleaf pine are also widening. As a timber commodity, shortleaf pine is inferior only to longleaf pine (Bray, 1904). Since the majority of Texas land is held by private landowners, the financial rewards for shortleaf restoration are promising, and would subsequently double as potential habitat for multiple wildlife species. Although more than 60% of shortleaf pine forests are owned by private landowners, between 2005 and 2012 shortleaf continued to be harvested and cleared at rates that exceeded renewal, leading to another five percent decrease (Anderson *et al.*, 2016). With the ever-increasing focus on the effects of climate change, shortleaf pine is also expected to be more resilient to these changes, while at the same time being able to meet numerous and varied management objectives that could continue to meet these goals for generations to come due to its elasticity and adaptability to a variety of environments and ecological parameters (Anderson *et al.*, 2016).

If properly managed, this synergy in land management practices, timber growth, and habitat restoration can provide landowners, counties, and states with economic incentives, while also providing safe-harbor for fragile plants and animals. For instance, habitat restoration efforts that benefit red-cockaded woodpeckers subsequently have beneficial effects for northern bobwhite, as well as white-tailed deer. Northern bobwhite, one of the most popular gamebirds in North America, have displayed downward trends similar to RCW's. In Georgia alone, northern bobwhite populations decreased approximately 85% since the 1960's (Georgia Department of Natural Resources, Wildlife Resources Division). The Bobwhite Quail Initiative, established in 1999, further echoes the loss of suitable habitat, and how the beneficial effects of ecosystem restoration for one species benefits many others. With RCW restoration efforts, habitat suitability is enhanced for northern bobwhite and optimal, improved bobwhite habitat further assists the potential prosperity for deer, wild turkey, and rabbits.

Longleaf Pine

Longleaf pine savannas are estimated to have once occupied approximately 92 million acres prior to European settlement. Of these 92 million acres, roughly 74 million were considered longleaf dominant, while the remaining 18 million were mixed with various hardwoods and other pine species (Frost, 1993). Currently, longleaf pine covers only three percent of its historic range, covering approximately three million acres (Frost, 1993). Frost (1993) attributes grazing by cattle and hogs, turpentine production, fire suppression, and hundreds of years of agriculture to the massive loss of longleaf pine.

The reduction of longleaf pine systems is not limited to a few states, but instead is pervasive throughout North America. In Georgia, what were once virgin longleaf forests and biologically diverse wiregrass systems are now overwhelmingly rural, having been converted into onion fields and various other agricultural products (Wetherington, 2006). Frost further refers to the exploitation of longleaf pine ecosystems and associated losses as a “milestone event…equal in scale and impact to the elimination of chestnut…” (Frost, 1993). This loss of habitat is considered the foremost reason for the significant decline of over 191 vascular plants and vulnerable wildlife species, such as the gopher tortoise (*Gopherus polyphemus*) and RCW (Landers *et al.,* 1995). Although longleaf pine is not currently as abundant as in the past, it still persists over most of its native range, making restoration of this ecosystem quite feasible (Brockway, 1997).

Similar to many other ecosystems in North America, longleaf pine forests are adapted to and dependent upon fire. Prior to European settlement, Native Americans and lightning strikes were the dominant ignition sources for landscape burns across the continent. Native Americans understood that periodic burning facilitated increased hunting opportunities, reduced fuel loads, and minimized the potentiality of wildfires (Van Lear *et al.,* 2005). The fire regimes in this system were characterized by frequent, low-to-moderate severity burns. Due to the grassy nature of the understory composition, low-severity burns were non-lethal to dominant vegetation and did not alter vegetative composition (Van Lear *et al.,* 2005). Furthermore, the fire return intervals were frequent enough (one to three years) that heavy accumulations of fuels did not occur. In fact, the fine, straight leaves of native bunchgrasses like bluestems (*Andropogon* spp.*)*, combined with the resinous, long needles of the pine trees ensured that landscape fires ignited quickly and readily spread across the ecosystems (Van Lear *et al.,* 2005). Today, many of these forests illustrate hardwood and shrub encroachment like the shortleaf systems, outcompeting and shading out native grass composition caused, in part, by years of fire exclusion or altered fire return intervals. Prescribed burns conducted by the NFGT aim to restore the open, grassy understory and promote biodiversity and healthy habitat conditions.

Longleaf pine ranges along most of the Gulf and Atlantic coastal plains and occurs on sites varying from poorly drained, wet flatwoods to dry mountain ridges (Landers *et al.,* 1995). It is a long-lived species, occasionally exceeding 500 years. Unlike many of the hardwood competitors, longleaf is considered an “intolerant pioneer.” The species has large seeds that fail to disperse over wide ranges, in addition to being a poor seed producer in general. Unlike shortleaf and loblolly, once seedlings germinate, they can remain in what is referred to as a “grass stage” for many years when competition is present (Landers *et al.*, 1995).

This competitive advantage of longleaf pine ecosystems is dependent upon complex interactions between fire, climate, and physiological conditions. However, frequent fires are the key to promoting and sustaining these forests. Not only does fire interval and severity play a role in longleaf pine development, but season of burns is also equally, if not more, important. Van Lear (2005) acknowledges that frequent fires during the *growing season* are key to preventing species in neighboring habitats from encroaching the longleaf pine systems while maintaining the open, pine-barren structure historically found within.

Longleaf pine timber is considered highly prized and of excellent quality, making a wide range of products from poles and pilings to plywood and pulp (Van Lear *et al.*, 2005). As a secondary benefit, these systems provide valuable habitat for a myriad of flora and fauna. Lastly, another recognized benefit of longleaf pine management is that once firmly established, longleaf is considered low-risk and adaptable to varying weather and site conditions.

Brockway (1997) describes eight benefits of periodic fire for longleaf pine success: 1) fire excludes invasive plants that are poorly adapted to burns which maintains the physiognomic character of longleaf pine savanna ecosystems; 2) prepares a favorable seedbed for longleaf pine seedlings; 3) reduces the encroachment and density of understory species, which in turn provides microsites for numerous herbaceous plants; 4) increases nutrient cycling for infertile soils; 5) improves forage for wildlife species; 6) enhances wildlife habitat; 7) helps to control pathogens and potentially damaging insects; and 8) reduces fuel levels and the potential for wildfire.

Loblolly Pine

Beginning in the early 1800's and extending to the 1900's, southern pinery's that were once largely longleaf shifted to predominantly loblolly (Schultz, 1997). This shift can be attributed to loblolly's rapid growth, tolerance to a wide array of soil and site conditions, and its ability to mitigate soil erosion (Schultz, 1997). Although the quality of timber attained from loblolly is not that of shortleaf and longleaf, these factors make loblolly pine one of the most economically important forest species in the southern US (Baker & Langdon, 1990). The range of loblolly extends through 14 states from Florida westward to Texas and north up the eastern coast into Delaware. Loblolly was considered a minor species in pre-settlement North American forests, being dominated by bottomland hardwoods in the lowlands and by longleaf pine in the uplands. Loblolly seeds heavily, easily regenerates, provides large timber yields at early ages, and can provide adequate wildlife cover and habitat in mixed-age stands (Schultz, 1997). Loblolly pines reach maturity around the age of 80. Succession, with the absence of disturbance factors, will result in a reduction of loblolly and the conversion into mixed hardwood systems (Schultz, 1997). Furthermore, a lack of disturbance also contributes to what is termed a "wildlife barren," where stands become too tall to serve as adequate deer browse, and competition reduces development for other beneficial plant species, illustrating the need for periodic prescribed fires and disturbances similarly required by longleaf and shortleaf species (Chen, Hodgkins, & Watson, 1975).

Most loblolly stands have a climate consisting of mild winters and long, hot, humid summers. Annual precipitation typically ranges between 40-60 inches, with a five month frost-free period in the north and a 10 month frost-free period in the south (Baker & Langdon, 1990). The most common soil order in loblolly's native range is Ultisols, with small pockets of Spodosols and Entisols, as well as Alfisols throughout the southeast (Baker & Langdon, 1990). Loblolly can be found associated with longleaf and shortleaf pines, as well as in pure stands and in combination with hardwoods, yellow poplars (*Liriodendron tulipifera*), and beeches (*Fagus* spp.). Natural loblolly stands, and to a lesser degree, intensely managed loblolly plantations, serve as habitat for a multitude of wildlife species such as squirrels (*Sciurus* spp.), white-tailed deer, northern bobwhite, and wild turkey, though not necessarily as importantly as shortleaf and longleaf systems.

Dormant Season vs. Growing Season Prescribed Burns

Ideally, prescribed fire effects should mimic those of natural fires that historically were a part of their respective environments. Unfortunately, due to personnel issues, operational constraints, liability limitations, and smoke management, the time of year when prescribed fires are able to be conducted can vary greatly. Further limitations, such as weather, budgetary constraints, and biological management where certain seasons can reduce the risk of injury to target species and personnel, can hinder timing of fires. Severe droughts increase the danger involved with prescribed burns, periods of prolonged rain will simply not allow an adequate-severity fire to spread, and excessive winds could potentially push a fire into developed or dangerous locations, for example, areas near residential or commercial properties.

Ecosystems where historically light to moderate fires burned are adapted and develop a resilience to the effects of these burns, allowing for regeneration and propagation of the species. Likewise, encroaching plant species that are not normally associated with their host cover types can be controlled and mitigated by these frequent, low severity fires. Furthermore, the *timing* (season) of prescribed fires can play an important role in allowing managers to more effectively shape the progression and composition of ecosystems. To be most effective, the season of burns should reflect the natural timing of historical fires that evolved alongside the ecosystem, unless intensive management and vegetation control dictates changes that would better meet management objectives and restoration goals (Table 1).

Table 1. Historical and prescribed fire seasons plus fuel consumption differences between dormant and growing season prescribed burns (from Knapp *et al.,* 2009).

Region	Historical fire season	Prescribed fire season	Fuel consumption difference between dormant and growing season burns
Western Forests	Dormant	Dormant/Growing	Very High
Southwestern Forests	Growing/Dormant	Dormant	High
Central Grasslands	Dormant/Growing	Dormant	Low
Southeastern Pine Forests	Growing	Dormant/Growing	Moderate
Eastern Hardwood Forests	Dormant	Dormant	Low to Moderate

When a plant is top-killed during a fire, the re-sprouting potential of the plant is dependent upon stored carbohydrates to rejuvenate and continue growing (Knapp *et al.,* 2009). Early in the growing season, carbohydrate reserves in plants are at a seasonal low. Therefore, when nuisance plant species are consumed during an early growing season burn (usually spring), the plant is much slower to rejuvenate, if it rejuvenates at all, which can lead to higher mortality and better compositional control. This research was in the southeastern US, where fires caused by lightning were most prevalent throughout the summer months, often peaking in May (Knapp *et al.*, 2009). Currently, most prescribed fires in the southeast occur during the dormant season, in contrast to the historical, natural regime. The concern is that continued burning during this dormant season will yield undesirable ecological conditions, which is evidenced by the composition that currently exists in the study sites and surrounding national forests. A contributing factor is that early research suggested to avoid spring and summer prescribed burns, as there were concerns that these fires would damage the trees and thus reduce timber profits (Bruce, 1954). However, southern pine trees are adapted to growing season fires, and studies have provided evidence that the season of burns does not affect longleaf pine mortality in any measurable or predictable way (Glitzenstein *et al.*, 1995).

In addition to the season of burns, prescribed fires may also differ in intensity. In the west, natural fires were most common during the dormant season. However, most prescribed fires are now conducted during the spring months when fuel moisture is higher. The higher fuel moisture reduces the amount of fuel consumed, likewise reducing the heat and intensity of the flames. In order to thoroughly and completely assess the role of season in relation to prescribed burn effects, the effects of fire intensity should also be fully examined (Knapp *et al.*, 2009).

By analysis of tree rings and fire scars, it is estimated that before European settlement, southern forests had a fire-return interval of approximately 15 years or less (Henderson, 2006). In longleaf pine and slash pine communities near the Gulf of

Mexico, fires historically occurred during the middle of the summer (April through August), again, due to high frequency of lightning between the dry and season and prior to summer rains (Henderson, 2006).

Aside from direct effects to overstory tree species, fire is also used to control the encroachment of various hardwood tree species and understory shrubs. Numerous studies have reported that southeastern prescribed burns conducted during the peak of pre-European fire season (May) in established stands diminished understory hardwood stem density and encroachment better than prescribed burns conducted at any other time of the year (Boyer, 1993; Streng *et al.*, 1993; Waldrop *et al.*, 1987). However, these results are only achieved if a burn is conducted annually or biannually, as one prescribed burn alone is not enough to accomplish the desired effects. Furthermore, annual prescribed burns are not necessarily ideal for all ecosystem components; pine systems usually need a few years free from fire in order to regenerate and/or accumulate enough litter and fuels to allow a fire to spread. In established stands where pine regeneration is not necessarily a predominant goal but is instead focused on hardwood and shrub mitigation and historical restoration, annual growing season burns may be the best first step in achieving favorable compositional shifts.

White-Tailed Deer and Prescribed Fire

White-tailed deer (WTD) are one of the most culturally recognizable and economically important animals in the U.S. Economically, the average individual deer hunter spends approximately $900 USD annually, contributing to a total $8.9 billion spent annually on hunting trips and equipment (USFWS, 2006), higher than the gross domestic product of many countries. For centuries, many Native Americans survived as hunters of WTD, harvesting approximately four to seven million deer annually. Currently, this annual harvest remains nearly the same, with the tradition of WTD hunting being carried through the ages and continuing into present generations.

Outside of being a vital food source for anthropogenic hunters and animal predators, deer are considered a keystone herbivore, playing an integral role in their ecosystems by influencing the composition and abundance of many plant species (Waller & Alverson, 1997). In areas where extremely high densities of deer occur, deleterious impacts can be contributed to over-grazing of target woody saplings and seedlings, as well as the transmission of diseases to domestic livestock. With economic, cultural, and ecological value, it is imperative for land managers to provide a balance in WTD populations in order to maintain healthy, thriving herds for hunting eudemonia as well as ecosystem diversity, overall health, and well-being.

One of the most notable factors contributing to white-tailed deer hunter happiness is the potential for taking large, well-antlered trophy bucks and healthy does. Besides some genetic expression, a major factor in superior antler growth and body condition is adequate nutrition (QDMA, n.d.). Luckily, in synergy with many southeastern ecosystems, white-tailed deer forage quite often responds favorably to prescribed burns (Masters *et al.*, 1996). Near the study sites within the national forests in east Texas, red-cockaded woodpecker management and habitat restoration is an important objective for the USFS. A part of this intensive management involves frequent prescribed fires. A conducted in RCW habitat in Arkansas describes the controversy surrounding single-species management that had been occurring for RCW's. The authors further provided evidence that the management activities for RCW also subsequently improved forage production, diversity, and nutritional quality for white-tailed deer compared to control sites (Masters *et al.*, 1996).

Like Texas forests, *growing season* burns were the natural fire regime in the area, and that growing season fires at three-year intervals better control hardwood stem encroachment compared to dormant season burns. Winter fires were presented to be less successful at controlling hardwoods as well as being unable to provide higher quality forage. Deer have a strong reliance on acorns and hard mast produced by oak trees when available, but the reduction of mast available to deer can be offset and balanced by more dependable and higher quality forage provided by prescribed fire and wildlife stand improvement activities (Masters *et al.,* 1996).

A major limiting factor for white-tailed deer is poor quality habitat. Maintaining superior habitat and high quality forage is essential for maximizing deer growth and abundance (Masters, Lochmiller, & Engle, 1993). Because prescribed fire positively correlates to improved forage and nutritional quality, this research further attempted to analyze if prescribed fire history can relate to an improvement in deer abundance and body condition. Furthermore, improved forage can directly correlate to improved physiology, so it is not unreasonable to assume that a direct relationship may be statistically corroborated.

TPWD is devoted to ecosystem management and restoration. Annually, TPWD establishes numerous check stations on the opening day of rifle season to monitor hunting regulations and collect information on all harvested deer. This information is stored for later analysis and involves recording multiple variables related to deer condition such as body weight and antler condition, as well as procuring samples to test for chronic wasting disease.

Likewise, the fire effects monitoring initiated by the forest service is an attempt to gather long-term data in relation to prescribed burn effects and ecosystem composition. This methodology involves capturing considerable amounts of information in the ecosystems. This protocol is therefore the foundation of the information used for analysis and data capture for this project, as well as for similar research projects in the future.

RESEARCH METHODS

Site Descriptions and Locations

The National Forests and Grasslands in Texas consist of approximately 640,000 acres of forests and 38,000 acres of grasslands. The forests are within the Piney Woods of eastern Texas, and are classified in the Humid Temperate Domain, Subtropical Division, and Southeastern Mixed Forest province (USFS, 1996). The sites where fuel plots were established are located in three Ranger Districts, interchangeably referred to as "National Forests": These districts are the Sabine/Angelina, Davy Crockett, and Sam Houston (Figure 2). The forests consisted of predominantly loblolly (*Pinus taeda*) and shortleaf pine (*Pinus echinata*) overstory, with occasional longleaf pines (*Pinus palustris*). Midstory ranged from predominantly sweetgum (*Liquidambar styraciflua*) in the Angelina region, to post oak (*Quercus stellata*) and hickory (*Carya* spp.) in Davy Crockett. The understory consisted of a heavy American beautyberry (*Callicarpa americana*) presence (>70% aerial cover in some areas), as well as sweetgum, oak saplings (*Quercus* spp.), yaupon (*Ilex vomitoria*). Recently, the invasive Japanese climbing fern (*Lygodium japonicum*) was discovered in these National Forests. Due to Japanese climbing fern being an exotic-invasive species, it presents further management implications and USFS personnel wanted to ensure that the species occurrence was recorded. When collecting the field data, all sites that had this species present were noted.

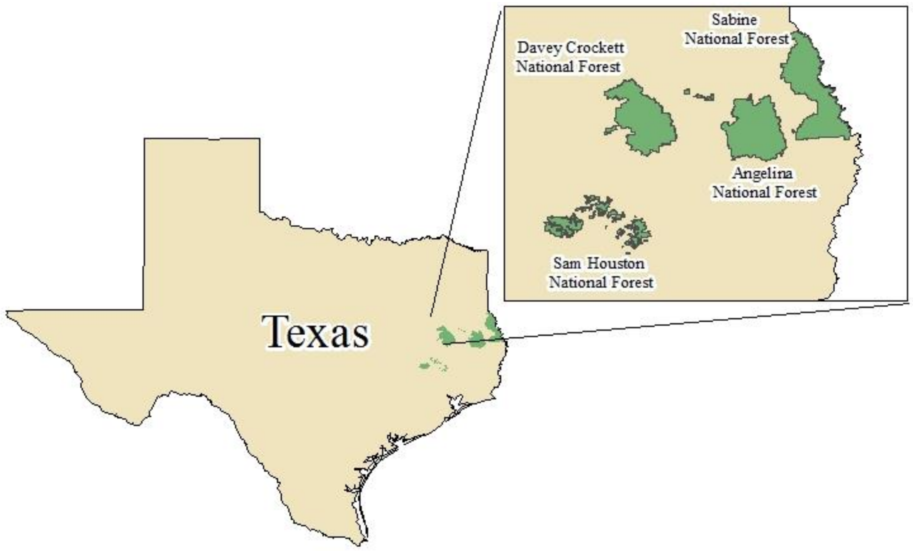

Figure 2. National Forest study areas in East Texas including the Angelina/Sabine, Davy Crockett, and Sam Houston National Forests (Image by Wall, 2017).

Historically, many of these forests had an "open, park-like structure" (called savannas), consisting of a predominantly native perennial bunchgrass understory layer, flowers, and sparse shrubs (Figure 3). After alterations of fire regimes, the basal areas of the forests increased and, as a result, the herbaceous grassy understory component began to be shaded out while creating favorable conditions for shade-tolerant hardwood and shrub encroachment (Anderson *et al.,* 2016). Currently, sites are dominated by large diameter pines with rare-to-minimal sapling regeneration where hardwood saplings such as oak, hickories, and sweetgum typically outnumber the pine saplings. The midstory in almost every plot has a significant hardwood component, while some are advancing into overstory classes. The understory was dominated by dense thickets of American beautyberry and yaupon, sometimes containing small pockets of moderately abundant narrowleaf woodoats (C*hasmanthium sessiliflorum*) and only occasionally, native perennial bunchgrasses, such as bluestem (*Andropogon* spp). In some areas, the understory contains such dense sweetgum and yaupon as to be one of the only visible components.

Figure 3. (**A**) Privately managed pine savanna in Nacogdoches County, TX in 2018 which can be considered representative of historical conditions. (**B**) Fire monitoring plot transect in the Sabine National Forest in 2018, 1 year after a prescribed burn (Photos by Wall, 2018).

Angelina/Sabine National Forests

The Angelina and Sabine National Forests are separate entities and ecosystems, but are now managed as a single Ranger District. The Angelina National Forest consists of approximately 150,000 acres of pine and hardwoods, with longleaf pine predominantly in the southern portion, and loblolly and shortleaf pine in the remaining areas (USFS,

1996) (Figure 4). The Angelina National Forest lies in Jasper, Angelina, Nacogdoches, and San Augustine counties, east of Lufkin, TX and divided by the Sam Rayburn Reservoir. Most of the prescribed burns are conducted January through March, with some burns being conducted in May. USFS personnel try to keep a 2-3 year fire rotation. Some of the most notable attributes include the Turkey Hill and Upland Island Wilderness Areas, as well as the Old Aldridge Sawmill site, Bannister Wildlife Management Area, and the Stephen F. Austin Experimental Forest. Recreational opportunities include miles of forested lakeshore along the Sam Rayburn Reservoir, multiple trails for hiking, as well as camping, fishing, hunting, and canoeing. The Sabine National Forest comprises approximately 160,000 acres primarily within the Sabine, Shelby, and San Augustine Counties. Significant attributes of this forest include the Indian Mounds Wilderness and multiple recreation sites, as well as several gas and oil wells. The USFS geographic project units describe the forest as shortleaf on the northern half, longleaf-shortleaf predominantly on the southern half, with a small southern band of longleaf overstory extending from west to east. On the eastern portion of the forest lies the Toledo Bend Reservoir, which provides a multitude of fishing, camping, and hiking opportunities along its lakeshore (United States Department of Agriculture, n.d.).

<u>Davy Crockett National Forest</u>

Davy Crockett National Forest comprises approximately 160,000 acres and lies within the counties of Houston and Trinity, west of Lufkin, TX and east of Crockett, TX. Most burns in Davy Crockett are conducted February through April on a 2-4 year rotation, though some plots had not been burned for 6-7 years. Important attributes of this national forest include the Big Slough Wilderness Area, Ratcliff Lake Recreation Area, Neches River, 4-C hiking trail, and the Piney Creek Horse Trail. It consists of pine-hardwood woodlands, with relatively flat or gently rolling topography. The USFS geographic project units describe the site as predominantly shortleaf sandhills in the northern portion, shortleaf-post oak (*Quercus stellata*) in the central area, and shortleaf-longleaf in the southern range (Figure 4). Midstory components consist of scattered oaks and various hardwoods. The understory consists of oak seedlings, yaupon, and American beautyberry. The forest is host to many wildlife species such as deer, quail (*Odontophoridae* spp.), dove (*Zenaida* spp.), wild turkey (*Meleagris gallopavo*), and the endangered red-cockaded woodpecker. Recreational activities include dispersed camping, hiking along the 20 mile 4-C trail, camping at the multiple maintained campgrounds in Ratcliff Lake Recreation Area, fishing, canoeing, hunting, and horseback riding (United States Department of Agriculture, n.d.).

Sam Houston National Forest

The Sam Houston National Forest comprises approximately 161,000 acres located within Montgomery, Walker, and Jacinto counties, roughly 60 miles north of Houston, TX. Most of the burns in Sam Houston are conducted in February through April on a 3-4 year rotation, though some compartments used in the analysis have not been burned for 9-10 years. Lake Conroe is a major water feature on the western portion of the forest. The forest has multiple recreation areas, in which Double Lake and Cagle receive the majority of recreationists. The northern forest is predominantly loblolly-post oak overstory while the southern portion maintains a loblolly-white oak overstory (Figure 4). The forest also has significant attributes within the Big Creek Scenic Area, Little Lake Creek Wilderness, as well as hiking opportunities along the Lone Star National Recreation Trail. The forest is host to a major population of the red-cockaded woodpeckers. Recreational opportunities include hiking, camping, hunting, and water activities such as fishing and boating (United States Department of Agriculture, n.d.).

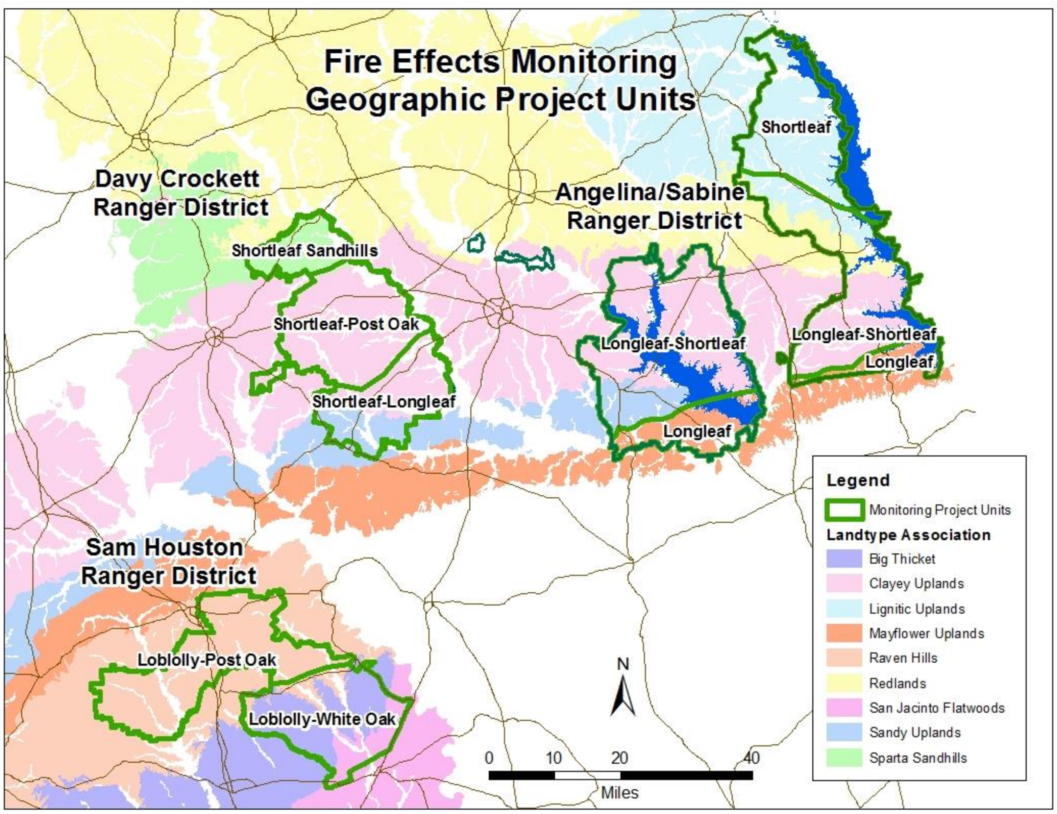

Figure 4. The United States Forest Service Geographic Project Units in East Texas for the Fire Effects Monitoring Program (Image used with permission from USFS Fuel Technician Gesse Bullock).

National Forests and Grasslands in Texas Management Objectives

The following generalized management objectives are considered representative examples for each national forest as of January 2018, and are taken from personal communication between the researcher and appropriate USFS representatives. These objectives are often subject to changes and alterations dependent upon ecosystem needs and various targeted goals.

Angelina/Sabine National Forest Burn Prescription Objectives

The following objectives are for a 4,943 acre area in Sabine National Forest located in what is called the "Brushy Creek" quadrangle. This area borders the Toledo Bend Reservoir as well as other USFS land and some private pastures and pine stands. The area has slopes ranging from 0-20% on fine sandy loam/loam soil profiles. The overstory consists of longleaf, shortleaf, and loblolly as both immature and mature sawtimber with a mixed upland hardwood component. The understory is considered grassy, with occasional yaupon, underbrush, and various hardwood seedlings. The Brushy Creek area has several special considerations which include 10 red-cockaded woodpecker clusters, areas that contain sensitive plants and streamside management zones (SMZ's), and heritage and historical resources that need protection, as well as the Ragtown Recreation Site located within the burn area. The primary resource objective is to reduce potentially hazardous fuel accumulations in order to minimize the risk of potential wildfires. Secondary resource objectives include promoting habitat for the red-cockaded woodpecker and increasing species diversity and abundance of native vegetation. The quantitative prescribed fire objectives are to reduce fuel hazards by: (1) minimizing the litter layer by 50-60%; (2) reduce <1" diameter class vegetation by 60-80%; (3) reduce 1-3" diameter class vegetation by 30-40%; and (4) reduce 3-9" diameter class vegetation by 20-30%.

Davy Crockett National Forest Burn Prescription Objectives

The 2,562 acre area in the Davy Crockett National Forest in compartments 62/95, approximately ½ mile north of Hwy 287 between Crockett and Groveton, TX, is described as mostly flat with elevations ranging between 275 and 350 feet. The burn plan consists of five resource objectives: (1) reduce fuels in order to reduce the potential for wildfire; (2) improve and concurrently maintain wildlife habitat, including the habitat of red-cockaded woodpeckers; (3) reduce hardwood midstory in order to promote the growth of native grasses in the understory; (4) improve nest and brood rearing habitat for game species such as white-tailed deer and eastern wild turkeys; (5) reintroduce and maintain prescribed fire within this ecosystem (NWCG Prescribed Fire Plan, 2017). The quantitative prescribed fire objectives aim to reduce fuel loadings to four to six tons per acre and to reduce 25-50% of sprouting understory species in order to improve current wildlife habitat.

Sam Houston National Forest Burn Prescription Objectives

There are four primary resources objectives for the Sam Houston Ranger District: (1) reduce the accumulation of fuels in order to protect both the forests and nearby private lands from potential wildfire; (2) improve red-cockaded woodpecker foraging habitat; (3) remove undesirable hardwoods from the midstory, while promoting a grass understory for browsing wildlife species; and (4) improve brooding and nesting habitat for such game species as the Eastern wild turkey. The primary objectives for the prescribed fire are to reduce fuel loads to four to six tons per acre and to reduce 25-50% of sprouting understory species that are less than 2” in diameter in order to improve the associated red-cockaded woodpecker habitat (Personal Communication, USFS 2018).

NFGT Monitoring Type Objectives

The monitoring types defined by the USFS and NFGT consists of: (1) Loblolly Pine-Post Oak (LBPOLM); (2) Loblolly Pine-White Oak (LBWOLM); (3) Shortleaf-Longleaf Gravelly Woodland (SHLLGR); (4) Shortleaf Pine-Post Oak Dry Loamy Woodland (SHPODL); (5) Longleaf Pine-Mixed Loamy Woodland (LLMXLM); and (6) Longleaf Pine-Bluestem Sandy Woodland (FLLBLSA) (McWhorter, 2012).

There were six monitoring types associated with this project. However, LBPOLM and LBWOLM were combined as the objectives were identical, and only one study plot was in the LBWOLM monitoring type.

Loblolly Pine-Post Oak & White Oak Objectives (LBPOLM/LBWOLM)

The USFS monitoring type description sheet describes the Loblolly Pine-Post Oak as a mixed pine and hardwood community, with loblolly and shortleaf pine being the dominant overstory species. Post oak, sweetgum, and hickory are also important canopy components. The understory components consists of beautyberry, yaupon, and swamp privet. The current fire return interval is 3-10 years. Defined management objectives for the LBPOLM/LBWOLM cover type include:

- Maintain understory woody, litter, and herbaceous fuel to < 6.72 tonnes/hectare and litter depths < 2.54 cm on a two year rough.
- Reduce understory woody and shrub cover to < 30%
- Increase cover of native grasses and forbs to > 35%
- Limit overstory mortality to < 5% within three burn cycles.

Shortleaf-Longleaf Gravelly Woodland Objectives (SHLLGR)

This monitoring type is a mixed pine-hardwood forest with pine usually accounting for > 70% of the cumulative basal area. Shortleaf and loblolly are dominant canopy species with occasional legacy longleaf components. Hardwood makeup consists of sweetgum, hickories, and post oak. The understory is dominated by grasses and shrubs with occasional forbs. The current fire return interval is 2-3 years. Defined management objectives for the SHLLGR cover type include:

- Maintain understory woody, litter, and herbaceous fuel to < 6.72 tonnes/hectare and litter depths < 2.54 cm on a two year rough.
- Reduce understory woody and shrub cover to < 25%
- Increase herbaceous understory cover to > 35%
- Limit overstory mortality to < 5% following three burn intervals.

Shortleaf Pine-Post Oak Dry Loamy Woodlands (SHPODL)

The SHPODL monitoring type is described as a mixed hardwood and pine community. Shortleaf is usually dominant but loblolly can also be dominant or co-dominant. Hickory, post oak, southern red oak, and sweetgums are important hardwood components. Midstory species can include redbud, elms, and dogwoods. Some important understory species are *Chasmanthium* spp., yaupon, and beautyberry. The current fire return interval is 2-3 years. Defined management objectives for the SHPODL are identical to SHLLGR which include:

- Maintain understory woody, litter, and herbaceous fuel to < 6.72 tonnes/hectare and litter depths < 2.54 cm on a two year rough.
- Reduce understory woody and shrub cover to < 25%
- Increase herbaceous understory cover to > 35%
- Limit overstory mortality to < 5% following three burn intervals.

<u>Longleaf Pine-Mixed Loamy Woodland (LLMXLM)</u>

LLMXLM cover type is usually dominated by longleaf with loblolly, slash pine, and shortleaf components. These forests were historically lacking hardwood species and had a diverse understory herbaceous component, but have since been converted to less favorable conditions over the years due to fire suppression and stand alterations. Due to this conversion, more hardwoods have encroached such as sweetgum, blackgum, and dogwood. Understory herbaceous species are commonly sparse due to woody encroachment. The current fire return interval is 1-2 years. Defined management objectives for the LLMXLM cover type include:

- Maintain understory woody, litter, and herbaceous fuel to < 6.72 tonnes/hectare and litter depths < 2.54 cm on a two year rough.
- Reduce understory woody and shrub cover to < 10%
- Increase herbaceous understory cover to > 60%
- Limit overstory mortality to < 5% following three burn intervals.

<u>Longleaf Pine-Bluestem Sandy Woodland (FLLBLSA)</u>

The FLLBLSA cover type is a mature longleaf pine stand with a minor shortleaf and loblolly component. These stands are also victim to fire suppression and display the same degraded and converted characteristics of LLMXLM. Most of these stands occur alongside red-cockaded woodpecker clusters and habitat. The current fire return interval is 1-2 years. Defined management objectives for FLLBLSA include:

- Maintain understory woody, litter, and herbaceous fuel to < 6.72 tonnes/hectare and litter depths < 2.54 cm on a two year rough.
- Reduce understory woody and shrub cover to < 20%
- Increase herbaceous understory cover to > 40%
- Limit overstory mortality to < 5% following three burn intervals.

FIELD METHODS AND DATA COLLECTION

Fire Effects Monitoring

The field design is a modified version of the Brown method (Brown, 1974) used by the National Park Service. Fuel plots were placed at stratified random locations within various compartments in each national forest. There are minimum total plot requirements that vary for each district, as well as minimum number of installations of new plots annually. The plot compartment locations, though random within each of the compartments themselves, were chosen based on differing levels of management importance and forest composition based on USFS preferences.

The plots consist of circles, with three transects extending to 16.3 meters from a permanently installed plot center (Figure 5). Plot center and the terminal points of each transect are composed of rolled metal stakes hammered into the ground. These stakes are permanent on the landscape and are usually marked with either spray paint or generously wrapped with flagging tape, as to help maintain visibility after prescribed burns. A random azimuth was selected for transect A, and the remaining transects were each established 120° clockwise from the last. For each transect, measuring tapes were attached to the plot center and extended to the terminal ends of each transect through the vegetation and as close to ground level as possible.

Along the three transects, herbaceous understory cover, duff, fuels, and downed woody debris was measured. Fuels were measured along the total length of each transect.

The fuels are categorized into 1 hour (< 0.63 cm), 10 hour (0.63 – 2.54 cm), 100 hour (2.54 – 7.62 cm), and 1,000 hour (7.62 – 20.32 cm) classes. Each fuel category were tallied and individual totals, as well as cumulative totals, were recorded. Each fuel classified as 1,000 hour was measured for diameter and identified as either solid or rotten. All trees allocated within the entire plot were recorded by species, DBH (diameter at breast height), overall health, any defects, and whether living or dead for both overstory and midstory. Overstory trees were those ≥ 15.24 cm in DBH and midstory trees were those ≥ 5.08 cm and < 15.24 cm. Aside from the physical attributes of the trees, the location of each trees stem is recorded and mapped. These maps allow researchers to easily and quickly locate the plot trees and assess any changes over time such as increase in tree diameters or overall compositional fluctuations.

Understory measurements were taken for vegetation < 5.08 cm in at least three 0.6 x 1.5 meter rectangular sub-plots (2'x 5'). These sub-plots begin at the 3 meter mark on the right of each transect and extend down the transect at 1.52 meter intervals. Understory herbaceous cover was measured, collected, and dried for further analysis and moisture content derivations, with later mathematics revealing tons per acre of litter, fuels, and duff. Stem counts for all woody and shrub species were tallied in each subplot and converted into stems per hectare. It should be noted that the stems per hectare are modeled conversions based on stem counts in the small subplots, and do not necessarily represent the hectares in totality, as the landscape is sometimes highly variable between plots. Two collection sub-plots were established 0.6 meters off of the left side of each transect at the 3 meters and 9.1 meter marks. These rectangular sub-plots measure 0.3 x

0.6 meters (1’x 2’) inside the rectangle, and constructed of carefully measured polyvinyl chloride (PVC) piping. Within these sub plots, litter and duff depth were measured to the nearest quarter of a cm (1/10th of an inch). The litter layer in one half of the subplot was collected and placed in labeled paper bags. The herbaceous species (grasses and forbs) were taken from the entire subplot and also placed in labeled paper bags. Ocular estimations of total visible herbaceous cover were also recorded. Five sub-plots were established 0.6 meters to the left of each transect beginning at the 1.5 meter mark and continue to the terminal ends of the transects at 3 meter intervals. Similar to the collection subplots, understory litter and duff depth (when applicable) were recorded within each of these subplots. At the silviculture lab in the Arthur Temple College of Forestry and Agriculture, the paper bag collections were oven dried at 60˚C for 48 hours and dry weight was recorded.

Circular Plot ~836 m^2 (16.3 meter radius) with 3 Transects (A, B and C)

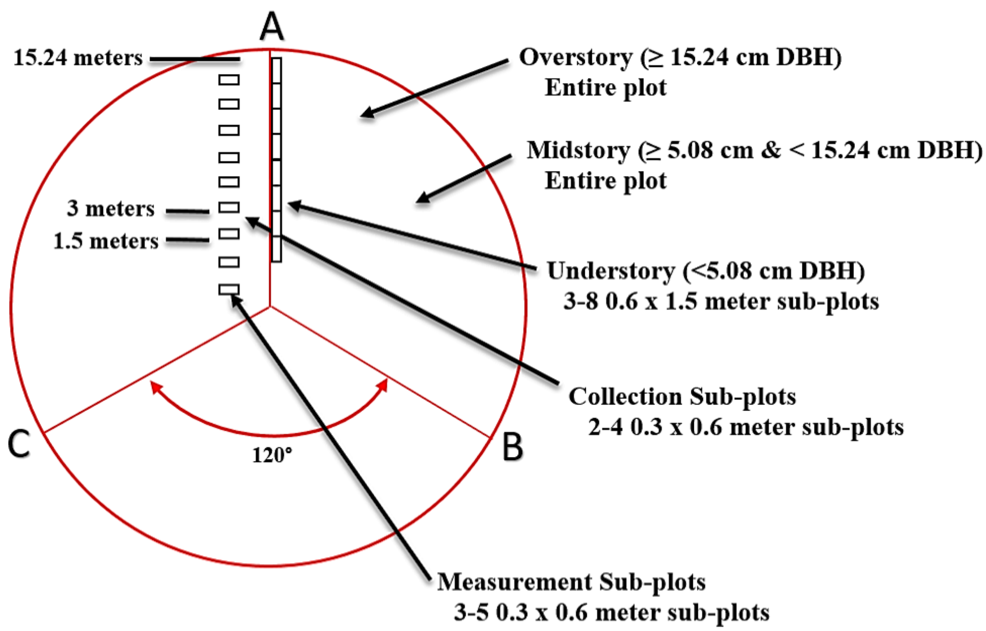

Figure 5. Plot design implemented during field research (Image taken and edited from USFS Revised Fire Effects Monitoring Plan, 2014).

White-Tailed Deer Methods

On the opening day of hunting season, the Texas Parks and Wildlife Department establishes check stations on their WMA properties. When hunters successfully harvest deer, the animals are brought to the check stations and data for the specimens are recorded. Recorded data includes age, date, field dressed weight of the deer, antler points, base, beam, and inside spread of the antlers, as well as any broken beams or defects. Although the data is recorded, statistical analysis of the records has not been performed. In conjunction with prescribed fire history within the WMA lands and neighboring properties, these records were analyzed for any significant statistical relationship. Depending on the WMA, the records in this study sometimes extend to the early 1990's, but due to the nature of the Forest Service's IFTDSS software and various time constraints, the years analyzed for this research aspect were 2010 through 2017. Secondly, due to the depth and scope necessary to accurately estimate abundance, the spotlight surveys were not used to garner population numbers, and research instead focused on antler sizes and body weight.

DATA ANALYSIS

Fire Effects Monitoring Plot Analysis

The collected datasets were analyzed for trends and composition based on the relationship to existing USFS management objectives and goals. The analysis aimed to illustrate changes over time and correlate these changes to prescribed fire regimes. Information related to the physical attributes of the forests current conditions were compared to the USFS's management goals to examine the effects of prescribed fire in successfully meeting these objectives. The majority of the analysis was statistically analyzed using IBM SPSS Version 23 (IBM SPSS, n.d.). Other relevant statistical software and fire monitoring programs such as FFI (FEAT/FIREMON Integrated) were used initially to analyze some preliminary trends, patterns, and fire history.

The dominant relationships were first identified by averaging the raw field data, converting relevant variables to tonnes/hectare (*t/ha*) using the Brown methodology, then comparing those results to current NFGT burn objectives and ecosystem goals defined by monitoring/cover type. The averages were totaled by plot, by National Forest, and then by NFGT monitoring type. ANOVA was bypassed for vegetation analysis due to the reduction in sample size caused by averaging the individual plots, where linear regression, bivariate correlation, and Pearson's *r* were used instead to statistically explain and substantiate ecological relationships, patterns, and conclusions. Furthermore, statistical analysis did not separate the data by monitoring type, as this caused such a decrease in sample size as to render results meaningless. However, this was not an issue as the effects that the dependent variables have on the independent variables would ecologically remain the same, regardless of anthropogenic, artificial "boundaries."

The results and predicted models shown by linear and bivariate regression illustrate changes over time in the forests associated with the study sites. Notable explanatory variables used by SPSS during regression analysis are the unstandardized coefficient (*b)*, multiple correlation coefficient (*R*), coefficient of determination (R^2), statistical significance (Sig. 1-tailed), as well as predicted values and residuals. The multiple correlation coefficient (*R*) represents a statistical and substantive descriptor. Statistically, *R* can be explained as displaying the effect and correlation the case values have on the dependent variable (Y) and their predicted values on the dependent variable (Y̌). Substantively, *R* represents the correlation between a set of independent variables and the dependent variable, similar in fashion to Pearson's *r,* except for multiple variables and not just two (Szafran, 2011). The coefficient of determination (R^2), shows how much of the resulting variability in the dependent variables can be explained by the effects of the independent variable. The coefficient of determination is a proportion ranging from 0 to 1, whereby multiplying this correlation by 100 yields percentages.

This analysis used Pearson's correlation (also known as Pearson's *r*) as the primary measure of association and bivariate correlation in which to describe the strength of the statistical relationships. It is important to note, however, that during *bivariate regression*, standardized coefficient values are identical to the Pearson's *r* value except that standardized coefficients do not indicate direction. Pearson's *r* ranges from -1.00 to 1.00. Higher numbers represent a stronger relationship while negative or positive numbers indicate direction. Szafran's criteria were used to describe the strength of relationships between variables (Szafran, 2011) (Table 2).

Table 2. Guide for defining the strength of a relationship (Taken from Szafran, 2011).

If the Absolute Value of a Measure of Association Is:	**The Relationship Will Be Described As:**
0.000	No Relationship
0.001 to 0.199	Weak
0.200 to 0.399	Moderate
0.400 to 0.599	Strong
0.600 to 0.999	Very Strong
1.000	Perfect Relationship

Multiple measurements were recorded for variables such as litter and duff depth, understory cover, fuels, etc., (as is protocol for the fire monitoring field methodology), and all numbers were averaged by individual plot. After compiling the averages by plot, the total averages were recorded by national forest (Davy Crockett, Sam Houston, and Sabine/Angelina). The management objectives pertaining to the study sites did not change based on individual forests, but were instead defined by USFS/NFGT monitoring types (used interchangeably here with "cover type"). Therefore, the averaged plot data was subsequently grouped based on the monitoring type objectives. The means that were considered borderline were classified as such based on a ± .10 cm margin of error.

Although the objectives did not change based on forest or district, the analysis still included the monitoring type objectives separated by each individual district in order to describe trends on a district level since the forests may have unique management operations, funding, and target goals or timelines. Furthermore, the goals defined by the NFGT's monitoring types are assessed on a 2-year rough (2 years post-burn), so the final averages excluded plots 3 years post-burn or older in order to meet the USFS's definitions. However, the sites on a 3-year rough or more are still described and illustrated to display vegetation that is currently on the ground. The understory woody component was converted into stems per hectare and the overstory trees were converted into trees per hectare, basal area, and basal area per hectare. The dry weight of the understory litter components was attained and converted into metric tons per hectare (t/ha). The expansion factor used to determine weight and vegetation per acre was 0.2064, representing just over one fifth of an acre ($5/64^{th}$ hectare) per plot, or approximately 8,990 ft^2 (835.2 m^2).

White-Tailed Deer Analysis

The relationship between white-tailed deer and prescribed fire was analyzed in SPSS using analysis of variance (ANOVA) with a 90% confidence interval. The dependent variables were total antler points, body weight, inside spread, base, and beam antler measurements, while the independent variable was years since the last prescribed burn. Historical records and information were identified through a relatively new program known as IFTDSS (Interagency Fuels Treatment Decision Support System) and FTEM (Fuel Treatment Effectiveness Monitoring).

A few limitations were encountered after analyzing and researching the white-tailed deer data. The WMA's used in the white-tailed deer analysis all have defined borders and associated compartments within the national forests, excluding Sam Houston National Forest. The entirety of Sam Houston is considered a WMA; therefore, the analysis excluded the Sam Houston deer population (approximately 35% of the total deer sample size) from the prescribed fire correlation and effects. These relationships could not be identified without first knowing the exact compartment where each deer was harvested in order to relate it to any prescribed fire effects. However, descriptive statistics for the age, weight, antler size, and sex ratio were still used to illustrate overall trends and patterns. Secondly, the TPWD data spans back many years and through various personnel and data recorders, so some minor portions of data were missing or incomplete. These missing variables were labeled as such in SPSS and are excluded from analysis, therefore "valid percent" is the variable reported in the analysis as it represents the percent of all *valid* cases that contain a valid value. The difference between standard percent and valid percent is that standard percent describes an attribute as a percentage of *all* cases in a data set, while valid percent describes the attributes as a percentage of *valid, present* cases (Szafran, 2011).

FEAT/FIREMON Integrated (FFI)

FFI is a relatively new monitoring application that is composed of two commonly used fire monitoring programs, FEAT and FIREMON, integrated into one software package. FEAT (Fire Ecology Assessment Tool) was created by the National Park Service and supplementary to the Fire Monitoring Handbook (FMH). FIREMON is a monitoring software package developed by the USFS. The goal in integrating the two was to increase interagency cooperation and improve the collection, analysis, and standardization of monitoring protocols. FFI allows the integrated use of components such as geographic information systems, data storage and entry, analysis of forest strata and fire effects, as well as summary reports (Lutes *et al.,* 2009). FFI, by design, maintains elasticity and flexibility, which allows it to be used in a variety of different ecosystems and forest types. FFI-Lite is a supplementary program added in 2015 which is designed to be used on field computers, increasing the accessibility of the program and allowing for an easier to maintain application for less extensive monitoring programs (Lutes *et al.,* 2009). FFI helps to further enhance data analysis by integrating various statistical and mathematical components, creating a 'one stop shop' for detailed analysis in lieu of extensive, time-consuming, and mathematically involved spreadsheet software.

IFTDSS and FTEM

IFTDSS is a program/website integrating multiple national agencies such as the USFWS, USFS, and NPS. The program seeks to enhance and provide more efficient analysis of fuel treatment planning and to expand and build a community of knowledge in regards to prescribed fires and wildfires. The program also provides step-by-step guides and an intuitive interface to digitally test and compare a variety of fuels treatment impacts and regeneration methods such as prescribed burns, clearcuts, and thins. This program can be used on multiple landscape scales and helps in the analysis of predictive behaviors and various models to aid in achieving the most effective and desired results. The program is also host to a large set of reference data from the entire United States, allowing agencies and users to upload fuels and fire information to the database (Hyde, n.d.).

FTEM is the Fuels Treatment Effectiveness Monitoring program which is used as a type of sister program to IFTDSS which provides an interagency 'hub' to help document the prevalence of wildfire and fuel treatment interactions (FTEM, n.d.). FTEM allows users to record as well as verify the effects of various types of fuel treatments initiated by federal agencies, congress, and even the public. It also identifies the extent of how hazardous fuel treatments interact with and affect the wildland-fire landscapes. FTEM also further documents when and how fuel treatments helped to minimize wildfire behavior or assisted in wildfire management. FTEM was used at a compartment and district level to analyze historical records such as season, date, time of burn, acres burned, location, and fire return interval.

RESULTS

USFS Fire Effects Monitoring Plots and Vegetation Results

USFS mean fuel loading and mean herbaceous cover goals were not met (0%) for any plot regardless of years since the last prescribed burn by district. Out of 24 total goals, only three met objectives and one was borderline, totaling 16.6% "success rate." Fuel loadings exceeded defined target weights and herbaceous cover targets were less than proposed goals. Mean litter depth did not meet goals except for the LBPOLM and LLMXLM monitoring types in Sam Houston and Sabine/Angelina. Woody and shrub objectives were not met except for in the Davy Crockett SHPODL cover type (Table 3).

Table 3. Surface fuel loadings, litter depth, understory herbaceous cover, and understory woody/shrub mean totals for all study plots for all years post-burn by National Forest and monitoring type.

Red = Objective Not Met, Gold = Borderline, Green = Objective Met

National Forest	Monitoring Type*	Fuel Load *(t/ha)*	Litter Depth *(cm)*	Herb Cover *(%)*	Woody *(%)*
Sam Houston	LBPOLM/LBW	31.53	2.44	17	61
	SHLLGR	29.87	3.14	14	64
Davy Crockett	SHPODL	37.68	2.58	35	24
Sabine/Angelina	SHPODL	35.73	2.69	24	32
	LLMXLM	34.05	2.14	43	38
	FLLBLSA	44.95	2.95	2	33

*USFS monitoring type codes. LBPOLM/LBW = loblolly pine-post oak/loblolly-white oak, SHLLGR = shortleaf-longleaf gravelly woodland, SHPODL = shortleaf pine-post oak dry loamy woodland, LLMXLM = longleaf pine-mixed loamy woodland, FLLBLSA = longleaf pine-bluestem sandy woodland.

When adjusted by *monitoring type* only, 0% of the plots met objectives for fuel loads, herbaceous cover, and woody percent. Out of 20 individual goals, two objectives were met and one was considered borderline, totaling 15%. The two litter depth objectives that were met were located in the LBPOLM and LLMXLM monitoring types, and the litter depth for SHPODL was considered borderline (Table 4).

Table 4. Surface fuel loadings, litter depth, understory herbaceous cover, and understory woody/shrub mean totals for all study plots for all years post-burn by monitoring type only.

Red = Objective Not Met, Gold = Borderline, Green = Objective Met

Monitoring Type*	Fuel Load *(t/ha)*	Litter Depth *(cm)*	Herb Cover *(%)*	Woody *(%)*
LBPOLM/LBW	31.53	2.44	17	61
SHLLGR	29.87	3.14	14	64
SHPODL	37.19	2.61	32	26
LLMXLM	34.05	2.14	43	38
FLLBLSA	44.95	2.95	2	33

*USFS monitoring type codes. LBPOLM/LBW = loblolly pine-post oak/loblolly-white oak, SHLLGR = shortleaf-longleaf gravelly woodland, SHPODL = shortleaf pine-post oak dry loamy woodland, LLMXLM = longleaf pine-mixed loamy woodland, FLLBLSA = longleaf pine-bluestem sandy woodland.

Since the targeted objectives outlined by the monitoring types are for 2-year roughs, any plots that were located in areas > 2 years since the last prescribed burn were removed from analysis. Objectives that are not met on a one or two year rough can be assumed to continue to not meet objectives in the future. Mean fuel loadings were not met on any district or monitoring type (0%). Out of 24 individual goals, five were met, totaling to 20.8%. Sam Houston National Forest met targets for litter depth and herbaceous cover for the LBPOLM cover type. Davy Crockett National Forest met all targets besides fuel loadings, and Sabine/Angelina only met targets for litter depth on the LLMXLM cover type (Table 5).

Table 5. Surface fuel loadings, litter depth, understory herbaceous cover, and understory woody/shrub mean totals for study plots ≤ 2 years post-burn by National Forest and monitoring type.

Red = Objective Not Met, Gold = Borderline, Green = Objective Met

National Forest	**Monitoring Type***	**Fuel Load** *(t/ha)*	**Litter Depth** *(cm)*	**Herb Cover** *(%)*	**Woody** *(%)*
Sam Houston	LBPOLM/LBW	34.64	1.58	35	51
	SHLLGR	29.87	3.14	14	64
Davy Crockett	SHPODL	38.66	2.71	43	22
Sabine/Angelina	SHPODL	35.73	2.69	24	32
	LLMXLM	42.04	1.70	50	35
	FLLBLSA	44.95	2.95	2	33

*USFS monitoring type codes. LBPOLM/LBW = loblolly pine-post oak/loblolly-white oak, SHLLGR = shortleaf-longleaf gravelly woodland, SHPODL = shortleaf pine-post oak dry loamy woodland, LLMXLM = longleaf pine-mixed loamy woodland, FLLBLSA = longleaf pine-bluestem sandy woodland.

When adjusted for *monitoring type* only, plots located on a 2-year rough or less also did not meet any fuel load objectives (0%). Out of 20 individual goals, 15% of objectives were met. Litter depth target goals were met on the LBPOLM and LLMXLM cover types, and herbaceous targets were met on the LBPOLM cover type; understory woody and shrub percent was borderline for the SHPODL cover type (Table 6).

Table 6. Surface fuel loadings, litter depth, understory herbaceous cover, and understory woody/shrub mean totals for study plots ≤ 2 years post-burn by monitoring type only.

Red = Objective Not Met, Gold = Borderline, Green = Objective Met

Monitoring Type*	Fuel Load *(t/ha)*	Litter Depth *(cm)*	Herb Cover *(%)*	Woody *(%)*
LBPOLM/LBW	34.64	1.58	35	51
SHLLGR	29.87	3.14	14	64
SHPODL	37.68	2.71	37	26
LLMXLM	42.04	1.70	50	35
FLLBLSA	44.95	2.95	2	33

*USFS monitoring type codes. LBPOLM/LBW = loblolly pine-post oak/loblolly-white oak, SHLLGR = shortleaf-longleaf gravelly woodland, SHPODL = shortleaf pine-post oak dry loamy woodland, LLMXLM = longleaf pine-mixed loamy woodland, FLLBLSA = longleaf pine-bluestem sandy woodland.

Regression, Bivariate Correlation, and Statistical Analysis

Linear regression was used to analyze multiple dependent variables including fuel loads, litter depth, understory woody percent, woody stems per hectare, and understory herbaceous percent to the independent variable "Years Since Burn". Linear regression was also used to identify and model any effects that woody percentages, woody stems per acre, and overstory trees per hectare have on litter, fuels, and herbaceous vegetation. Due to limited sample cases and variability in the original data set, regression results were inconclusive for total fuels in relation to years since last burned.

Regression for total tonnes per hectare did not yield any usable results, most likely due to variations in data recorders and forest composition. However, litter tonnes per hectare showed a moderate positive correlation to years since burn ($r = 0.306$). The predicted model shows that each year since a prescribed fire, fuel accumulates at the rate of 0.56 tonnes per year ($b = 0.561$). Approximately 10% of the differences seen in litter depth can be attributed to its relationship to prescribed fire (R^2 = 0.094), suggesting that other variables are the dominant contributor of tonnes of litter (Figure 6).

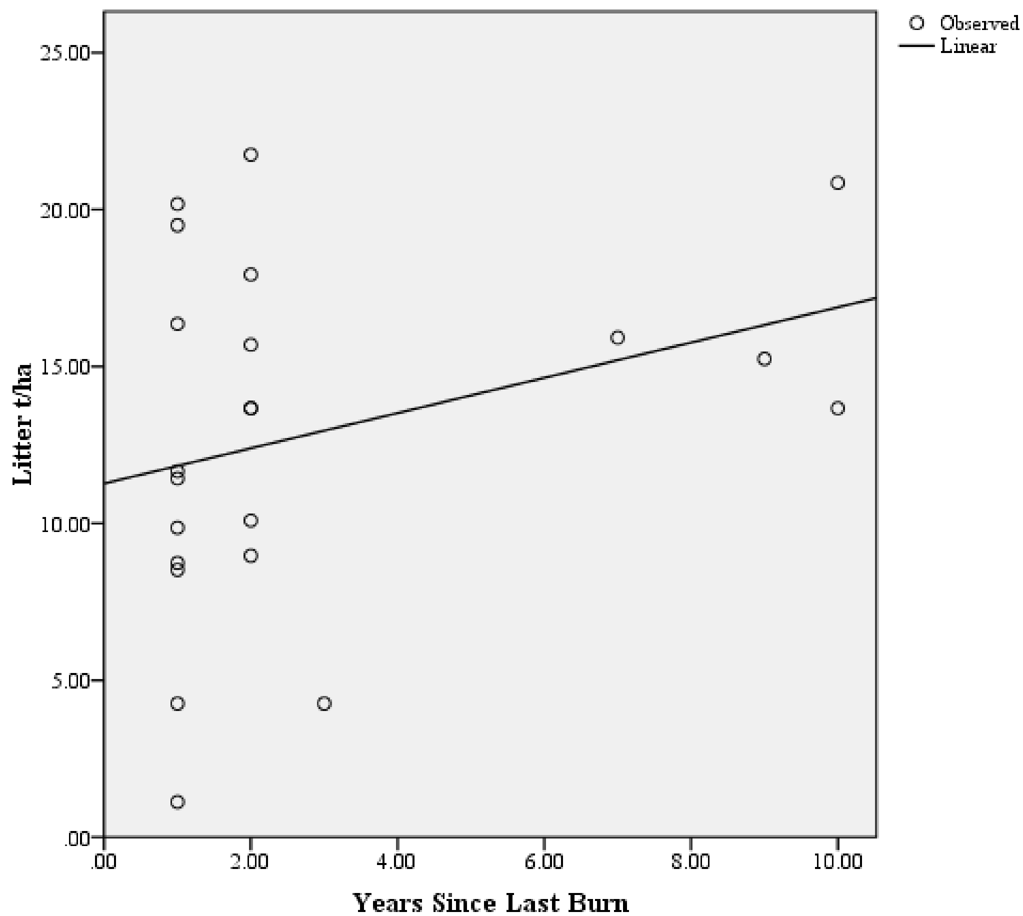

Figure 6. Linear curve estimation showing changes in litter t/ha in relation to years since the last prescribed burn.

Litter depth was also shown to have a moderate positive relationship to years since the last prescribed burn (*r* = 0.254). Not controlling for other variables, the model predicts that each year since a prescribed fire the litter depth increases by .08cm (*b* = 0.078). Approximately 6.5% of the differences in litter depth can be explained by years since the last burn (R^2 = 0.064) illustrating that there are most likely other factors contributing to the depth of litter in these forests (Figure 7). However, only five measurements were recorded between years 4 and 10.

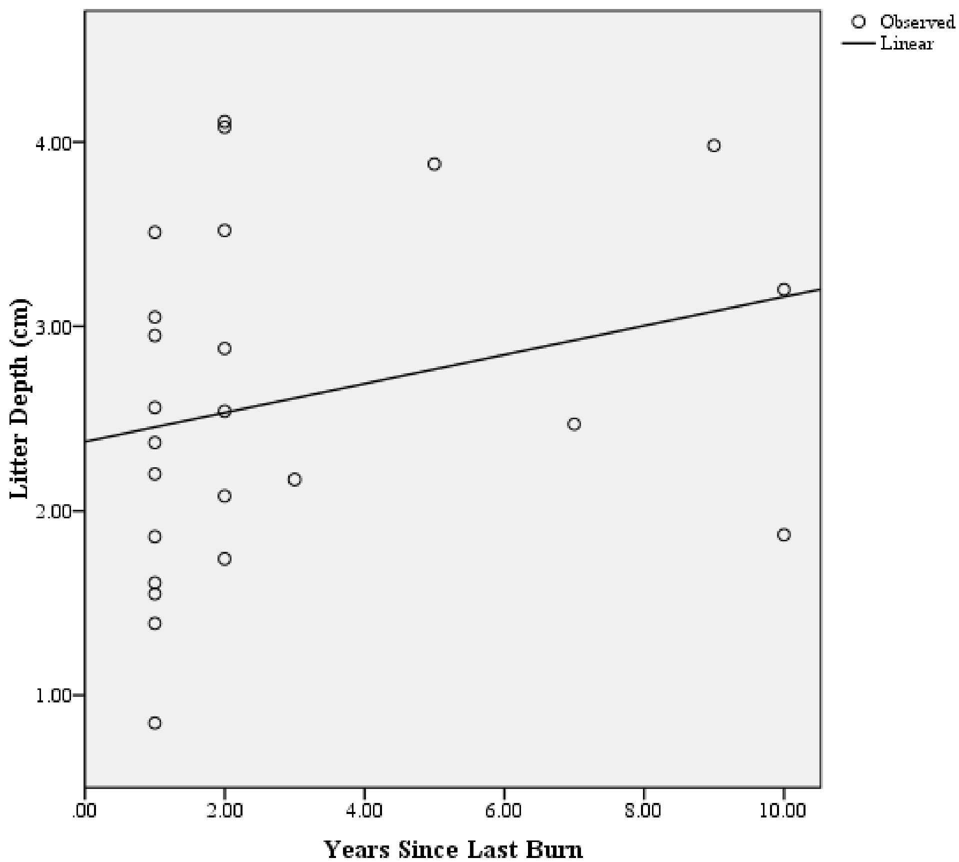

Figure 7. Linear curve estimation showing changes in litter depth in relation to years since the last prescribed burn.

Understory woody percentages showed a moderate positive relationship to years since the last prescribed burn (r = 0.330), as the percentage of woody cover and associated density increases as years pass since the last prescribed burn. Not controlling for other variables, the percentage of woody cover increased by 2.4% each year (b = 2.366). 10.9% of the differences in understory woody cover can be explained by prescribed burns (R^2 = 0.109), so it appears there are other factors contributing to the percentage of understory woody cover (Figure 8).

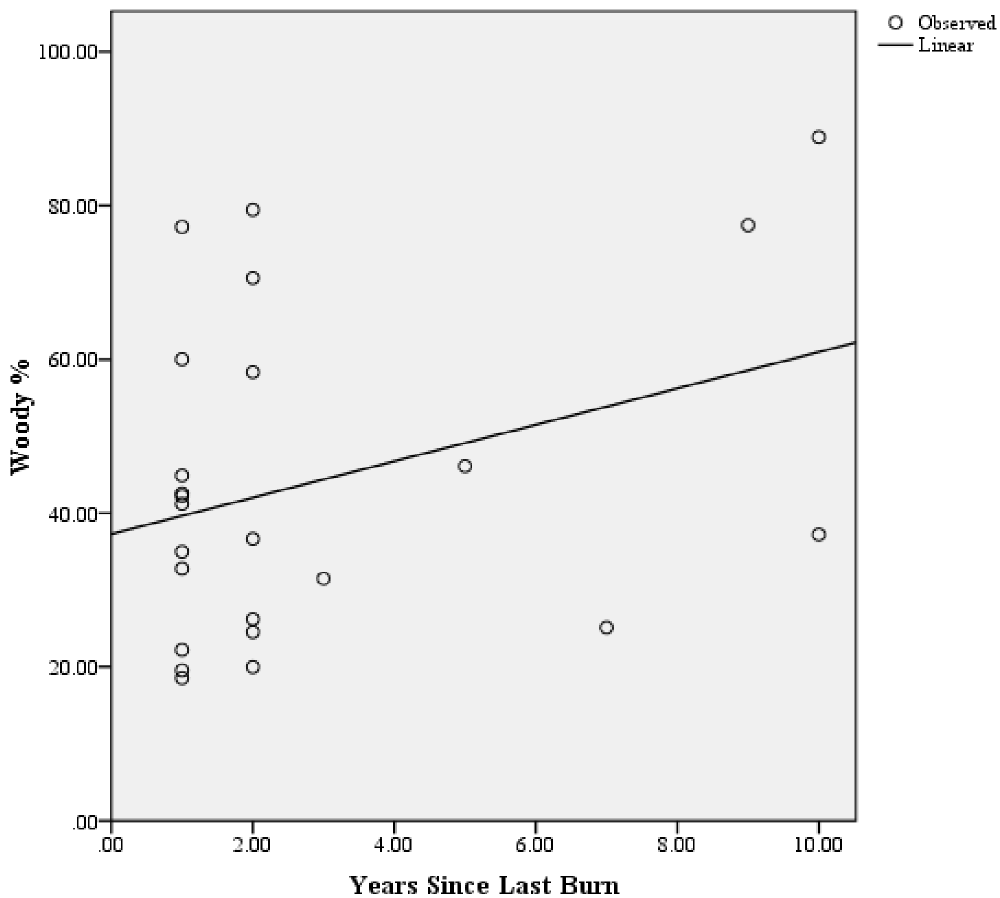

Figure 8. Linear curve estimation showing changes in understory woody and shrub percentages in relation to years since the last prescribed burn.

Woody stems per hectare were also regressed in relation to years since the last prescribed burn. Woody stems per hectare displayed a strong positive relationship to burn years (r = 0.571). The predicted model suggests that the abundance of woody stems increases substantially as years pass since the last burn. Without controlling for other variables, the number of stems increased by ~11,200 stems per hectare every year (b =

11,189.895). Around 33% of the differences in woody stem density can be attributed to prescribed fire (R^2 = 0.326), which suggests that frequent fire plays a very important role in limiting the encroachment of woody stems and shrubs (Figure 9).

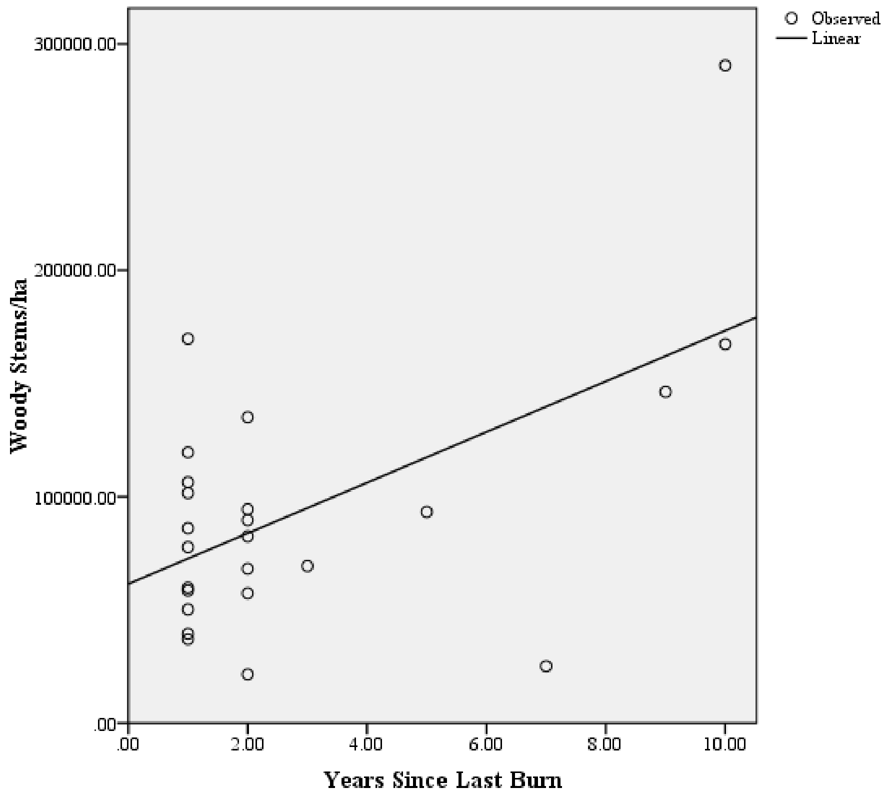

Figure 9. Linear curve estimation showing changes in understory woody and shrub stems per hectare in relation to years since the last prescribed burn.

Regression results for understory herbaceous cover suggests that frequent fire is important for the perpetuation of herbaceous species. The correlation shows a strong negative relationship between herbaceous cover and years since the last prescribed burn (r = -0.473). Not controlling for other variables, the predicted model suggests that herbaceous plant cover decreases by about 3% each year post-burn (b = -3.248). Over

22% (R^2 = 0.224) of the differences in herbaceous cover can be attributed to the years since a prescribed fire (Figure 10).

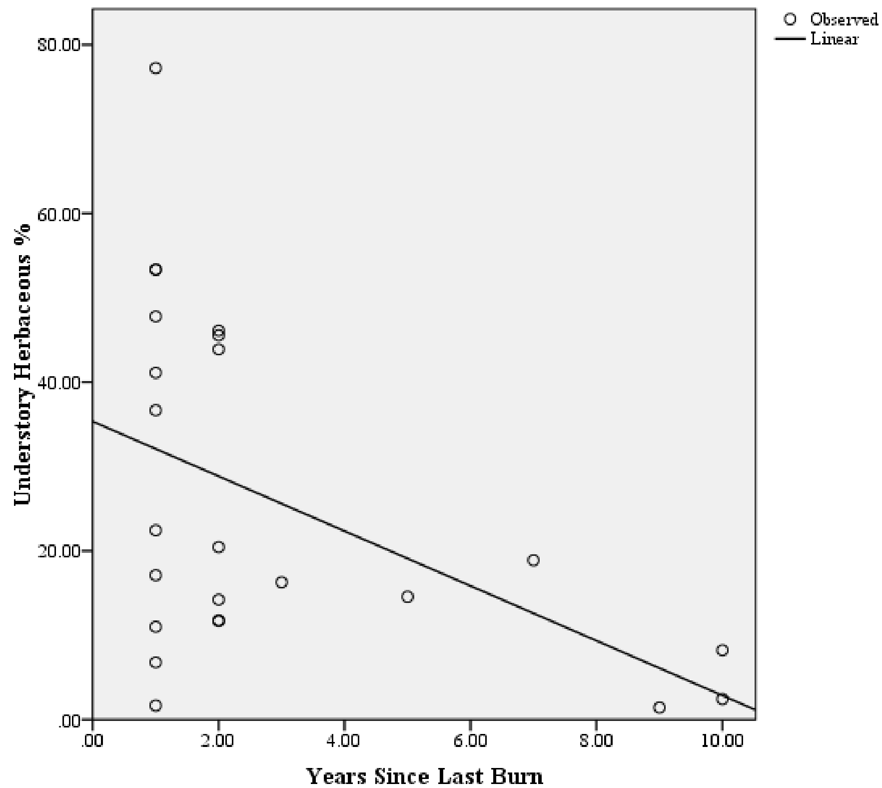

Figure 10. Linear curve estimation showing changes in understory herbaceous cover in relation to years since the last prescribed burn.

Due to R^2 values suggesting evidence that other variables were possibly contributing to fuel loads, herbaceous cover, and woody stems, further regression analysis explored the relationship between overstory trees and litter. Relationships between woody stems and herbaceous as well as overstory trees to herbaceous cover were also analyzed.

The relationship between overstory trees to total fuel loads and herbaceous cover showed weak correlations (r = 0.108 and -0.166). However, Pearson's r does show that as overstory trees per hectare increases, understory herbaceous percent decreases. A very strong correlation was shown between overstory trees and litter tons (excluding downed woody fuels) (r = 0.617). As overstory trees become denser, litter accumulation increases significantly. Not controlling for other variables, the model predicted that each tree contributes to 0.03 tons of litter per hectare (b = 0.030). Almost 40% (R^2 = 0.381) of the variability seen in the amount of litter per hectare can be attributed to tree basal area (Figure 11).

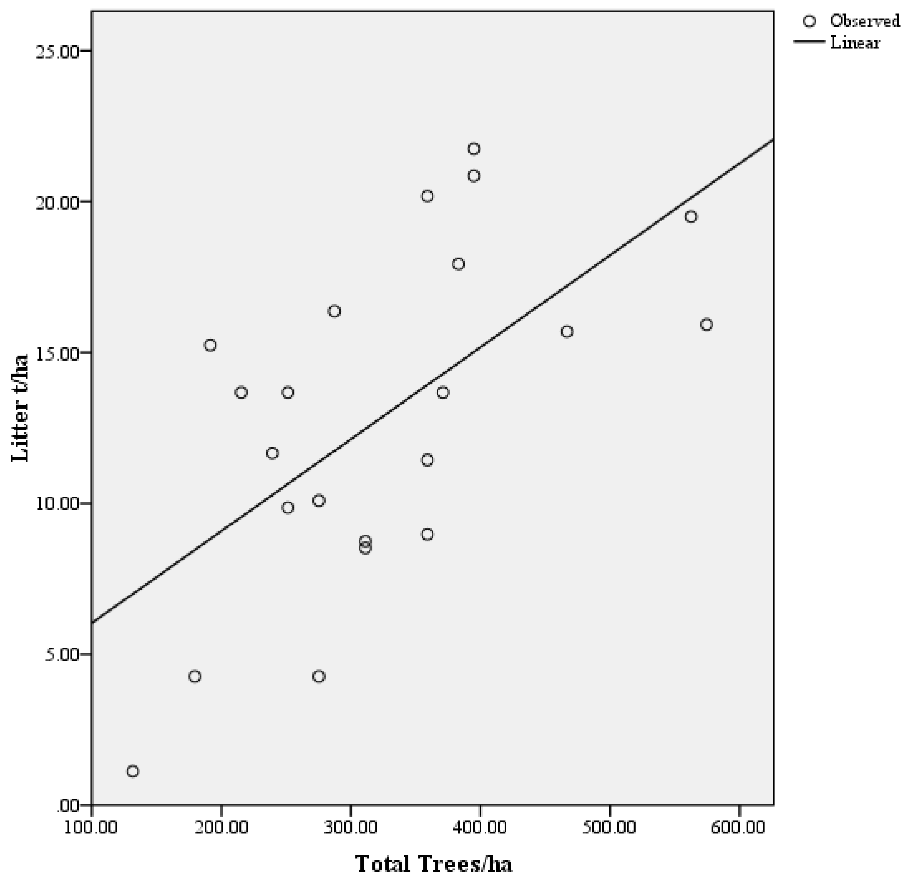

Figure 11. Linear curve estimation showing an increase in litter accumulation in relation to total trees per hectare.

The final regression analysis explored the relationship between herbaceous cover and woody stems per hectare. The results showed a strong negative correlation between herbaceous cover and stems per hectare (r = -0.507). This result indicated that herbaceous cover percent is heavily impacted by woody stems, and decreases exponentially in response to an increase in stem densities. Without controlling for other variables, approximately 26% of the difference observed in herbaceous cover can be contributed to woody stems per hectare (R^2 = 0.257) (Figure 12).

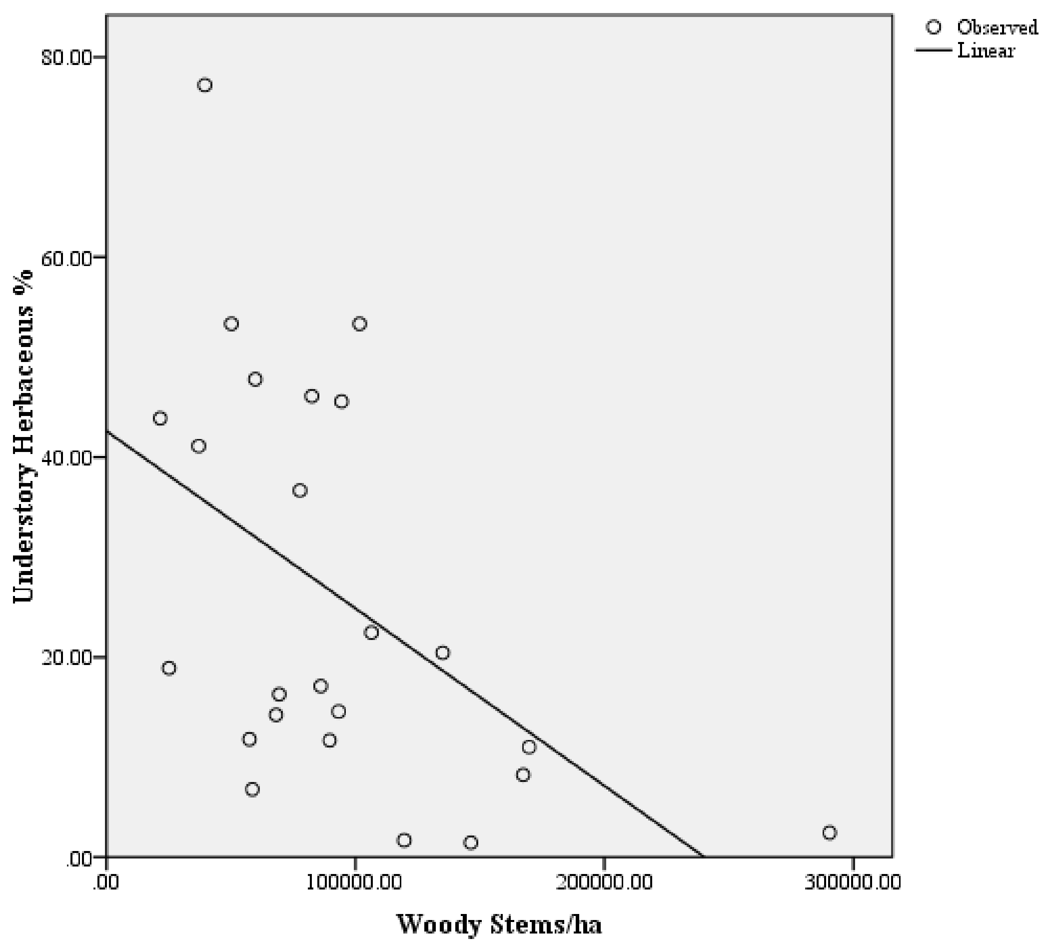

Figure 12. Linear curve estimation showing a decrease in herbaceous cover relation to woody stems per hectare.

White-Tailed Deer Results

The sex ratio of harvested deer consisted of 71% male and 29% female (2.3:1 m/f ratio) (Figure 13). The majority of deer were harvested in Sam Houston National Forest (35%) and Moore Plantation in Sabine National Forest (29.3%). Total deer harvested on opening day of rifle-hunting season between 2010 and 2017 was roughly 549 deer. The age of deer spanned 0.5 years and 6.5 years of age, with the highest proportion of harvested deer being 2.5 years of age (28.9%). The mean age was 2.62 years old with a standard deviation of 1.34 (Table 7).

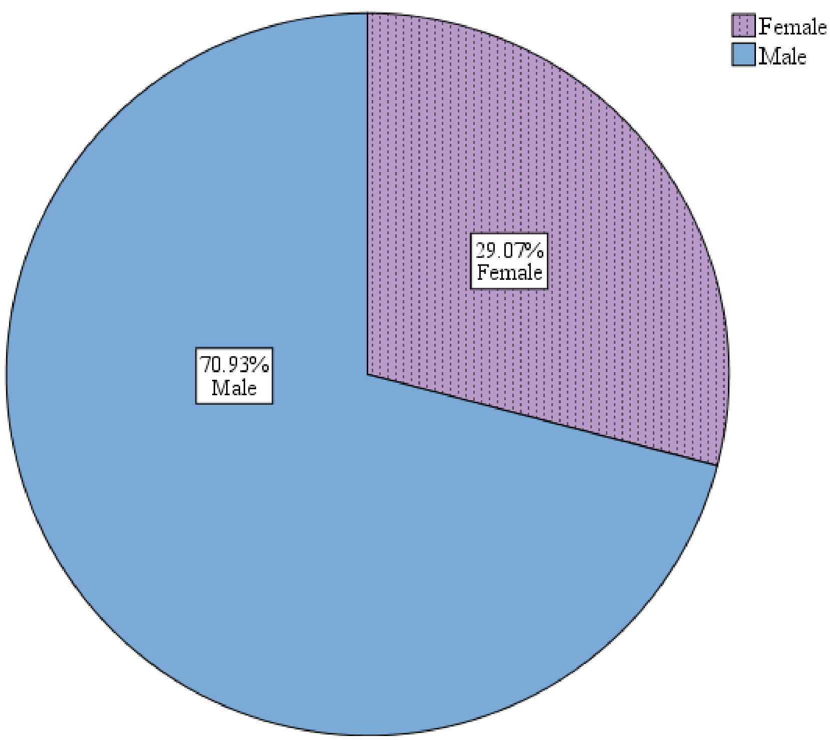

Figure 13. Sex structure of all white-tailed deer recorded at check stations during opening day of rifle-hunting season between 2010 and 2017 in Alabama Creek, Bannister, Moore Plantation, and Sam Houston National Forest in East Texas.

Table 7. Location of harvests, year of harvests, age, and sex of all white-tailed deer recorded at check stations during opening day of rifle-hunting season in Alabama Creek, Bannister, Moore Plantation, and Sam Houston National Forest in East Texas.

		Frequency *(n)*	**Valid Percent** *(%)*
Location	Alabama Creek	99	18.0
	Bannister	97	17.7
	Moore	161	29.3
	Sam Houston	192	35.0
	Total	*549*	*100.0*
Year	2010	64	11.7
	2011	107	19.5
	2012	43	7.8
	2013	97	17.7
	2014	94	17.1
	2015	22	4.0
	2016	77	14.0
	2017	45	8.2
	Total	*549*	*100.0*
Age	0.5	49	9.0
	1.5	145	26.7
	2.5	157	28.9
	3.5	116	21.4
	4.5	48	8.8
	5.5 +	28	5.2
	Total	*543*	*100.0*
Sex	Male	388	70.9
	Female	159	29.1
	Total	*547*	*100.0*

The majority (30.2%) of harvested deer weighed between 30-39 kg with a mean body weight of 33.9 kg (74.7 lbs) (Figure 14). Most deer were harvested the same year as a prescribed fire (55.4%), while hunter frequency and deer harvests dropped as years since last burn increased (Table 8).

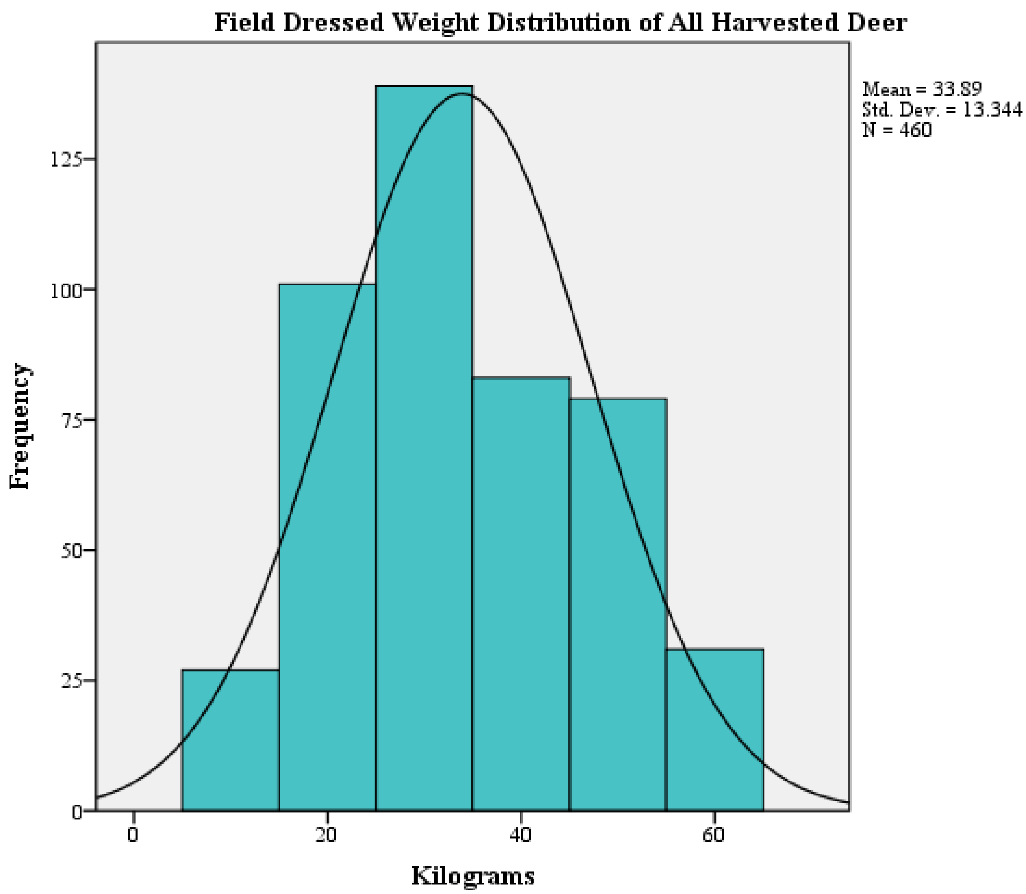

Figure 14. Field dressed weight distribution of all white-tailed deer recorded at check stations during opening day of rifle-hunting season in Alabama Creek, Bannister, Moore Plantation, and Sam Houston National Forest in East Texas between 2010 and 2017.

Table 8. Frequency of all white-tailed deer harvests in relation to years since last prescribed fire at check stations during opening day of rifle-hunting season in Alabama Creek, Bannister, Moore Plantation, and Sam Houston National Forest in East Texas between 2010 and 2017.

Years Since Burn	Frequency (n)	Valid Percent (%)
0	144	55.4
1	76	29.2
2	33	12.7
3	7	2.7
Total	*260*	*100.0*

Antler base, beam, inside spread, and total points were quantified for male deer ≥ 1.5 years old. For analysis of total antler points, spike and nubbin bucks (<1 point) were removed from the analysis. If included, the mean antler measurements would be noticeably smaller and would bias the analysis for the total adult buck population. The mean number of antler points for harvested males was 6 points, with approximately 50% of harvested males ranging between 7-10 points (Table 9). Most male deer ≥ 1.5 years old (32.5%) had a base measurement ranging between 80-99 mm with a mean base measurement of 65.8 mm (Figure 15). The average beam measurement recorded was 297.8 mm, with the highest proportion ranging between the 400-449 mm class (Figure 16). The inside spread measurements averaged 269.1 mm with a majority of harvests (43.2%) ranging between the 300-399 mm classes (Figure 17).

Table 9. Total antler point distribution of white-tailed deer males ≥ 1.5 years of age with at least 1 point recorded at check stations during opening day of rifle-hunting season in Alabama Creek, Bannister, Moore Plantation, and Sam Houston National Forest in East Texas between 2010 and 2017.

Total Points *(#)*	**Frequency** *(n)*	**Valid Percent** *(%)*
1	1	0.3
2	95	27.6
3	25	7.3
4	5	1.5
5	8	2.3
6	8	2.3
7	26	7.6
8	109	31.7
9	35	10.2
10	20	5.8
11	7	2.0
12	2	0.6
13	1	0.3
14	1	0.3
15	1	0.3
Total	344	100.0

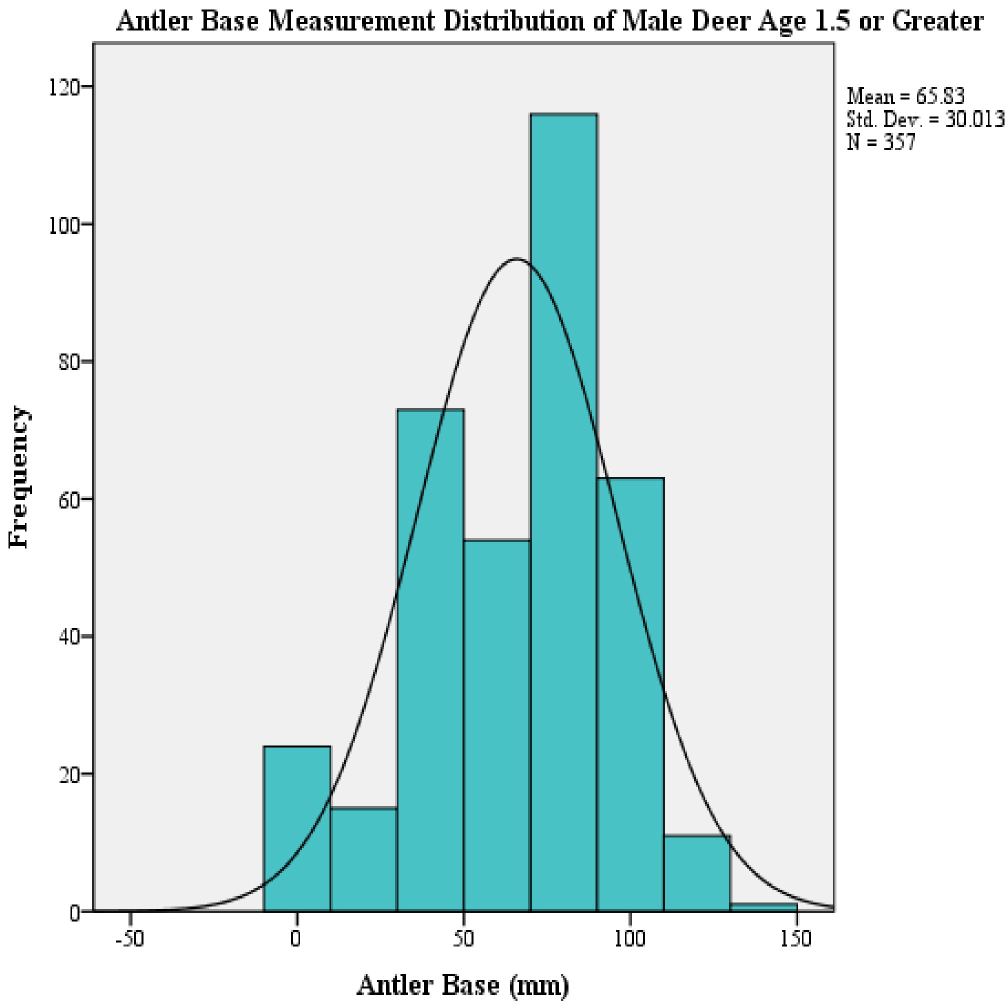

Figure 15. Base measurement distribution of white-tailed deer males ≥ 1.5 years of age recorded at check stations during opening day of rifle-hunting season in Alabama Creek, Bannister, Moore Plantation, and Sam Houston National Forest in East Texas between 2010 and 2017.

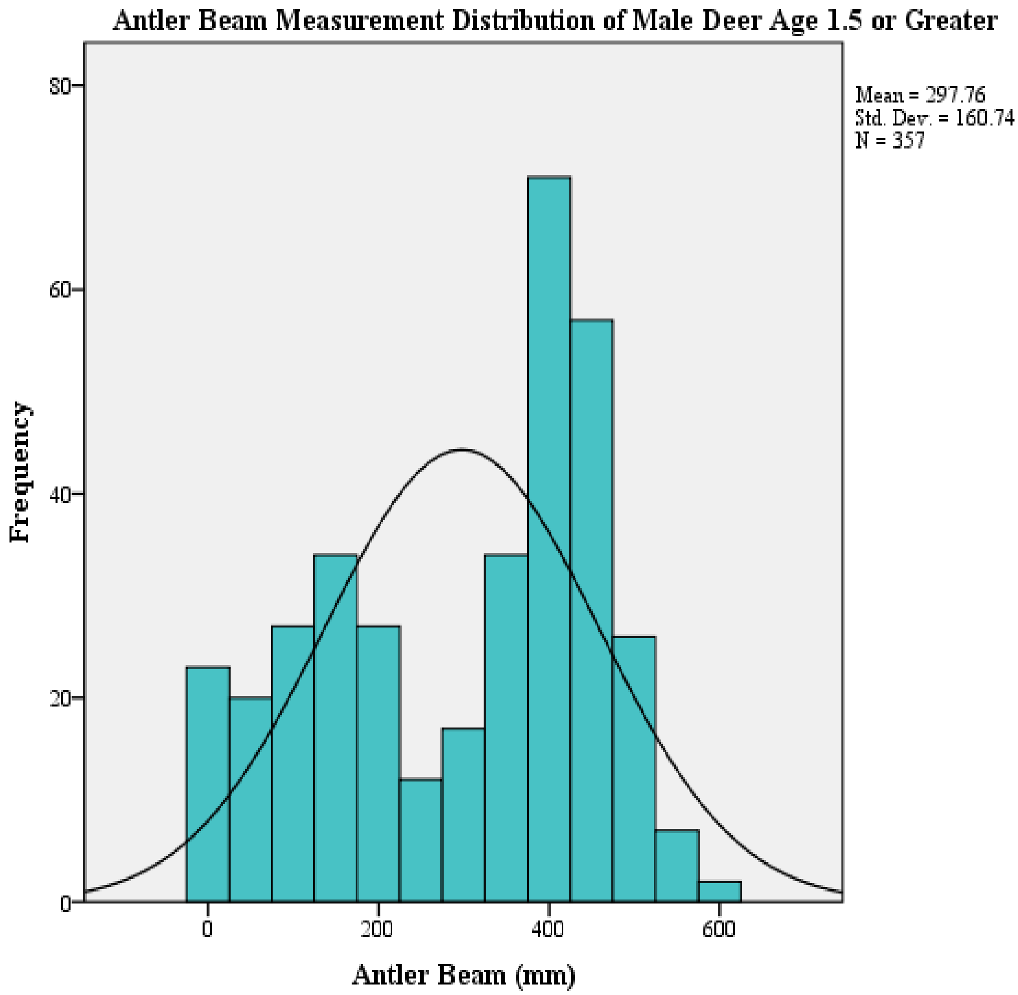

Figure 16. Beam measurement distribution of white-tailed deer males ≥ 1.5 years of age recorded at check stations during opening day of rifle-hunting season in Alabama Creek, Bannister, Moore Plantation, and Sam Houston National Forest in East Texas between 2010 and 2017.

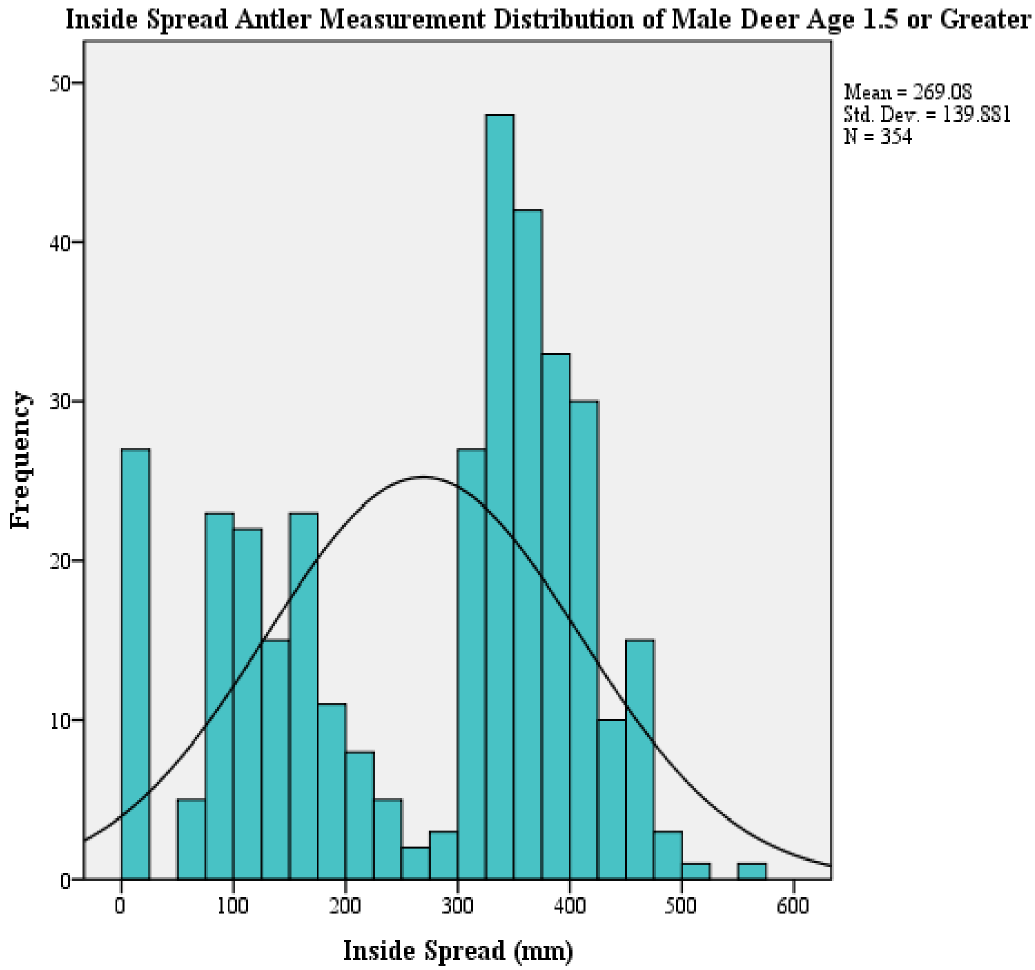

Figure 17. Inside spread distribution of white-tailed deer males ≥ 1.5 years of age recorded at check stations during opening day of rifle-hunting season in Alabama Creek, Bannister, Moore Plantation, and Sam Houston National Forest in East Texas between 2010 and 2017.

Analysis of Variance (ANOVA)

One-way ANOVA ($p \leq 0.1$) compared the dependent variables "body weight" and antler measurements "total points," "base," "beam," and "inside spread." The independent variable was "years since burn." To reduce the chance of making type I errors, the Tukey test was used as a post-hoc multiple comparison for significant results. Deer body weight, total antler points, and antler base did not show a statistical significance in relation to prescribed burns, but antler beam and inside spread measurements both displayed significance. For body weight, total points, and antler base, a trend was discovered where all variables peaked 2 years post-fire.

For total body weight, there were differences in the mean, but they were not statistically significant (F = 1.492, df = 3 and 222, p = 0.218). The body weights ranged between 10 and 60 kilograms, where deer weight 0 years since a burn had a mean of 33.7 kg while body weight peaked at 2 years since a burn with a mean of 39.1 kg (Figure 15).

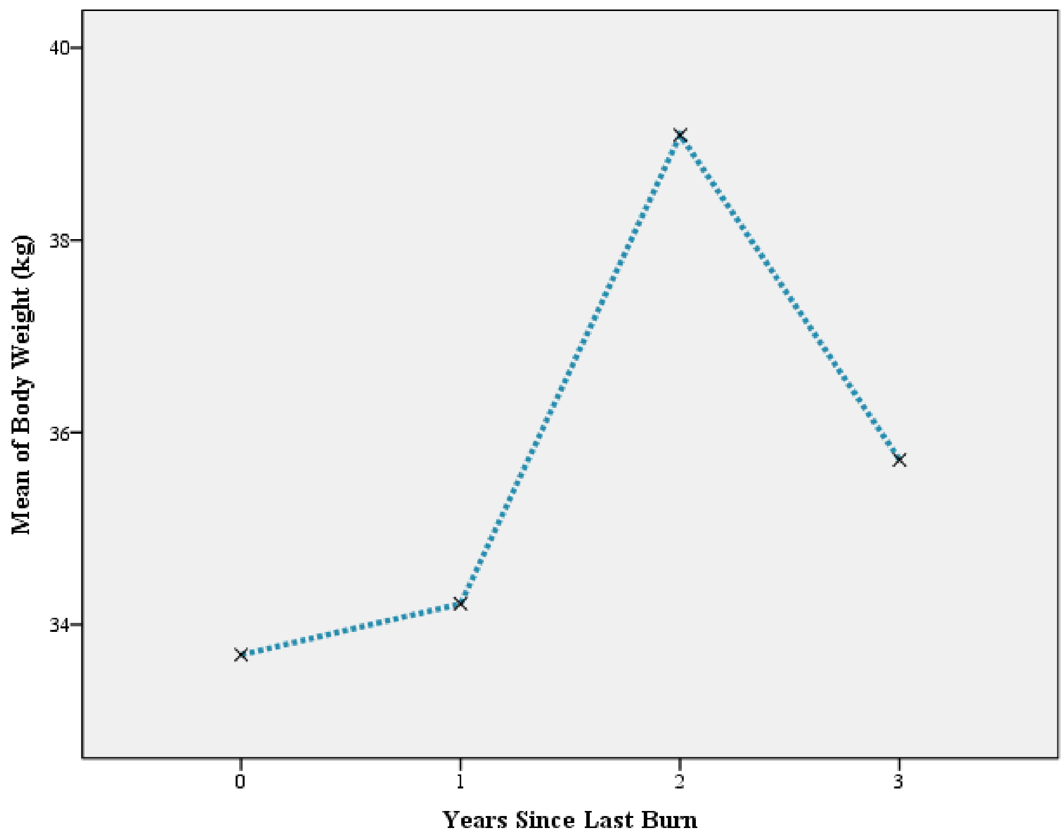

Figure 18. ANOVA results showing average white-tailed deer body weight in kilograms for the study population 0, 1, 2, and 3 years post-burn.

The differences between total points in relation to prescribed burn years were not statistically significant (F = 0.650, df = 3 and 171, p = 0.584). Total points ranged from 0 to 13, where deer antlers had an average of ~6 points one year post-burn and peaked 2 years post-burn with a mean of ~7 points (Figure 16).

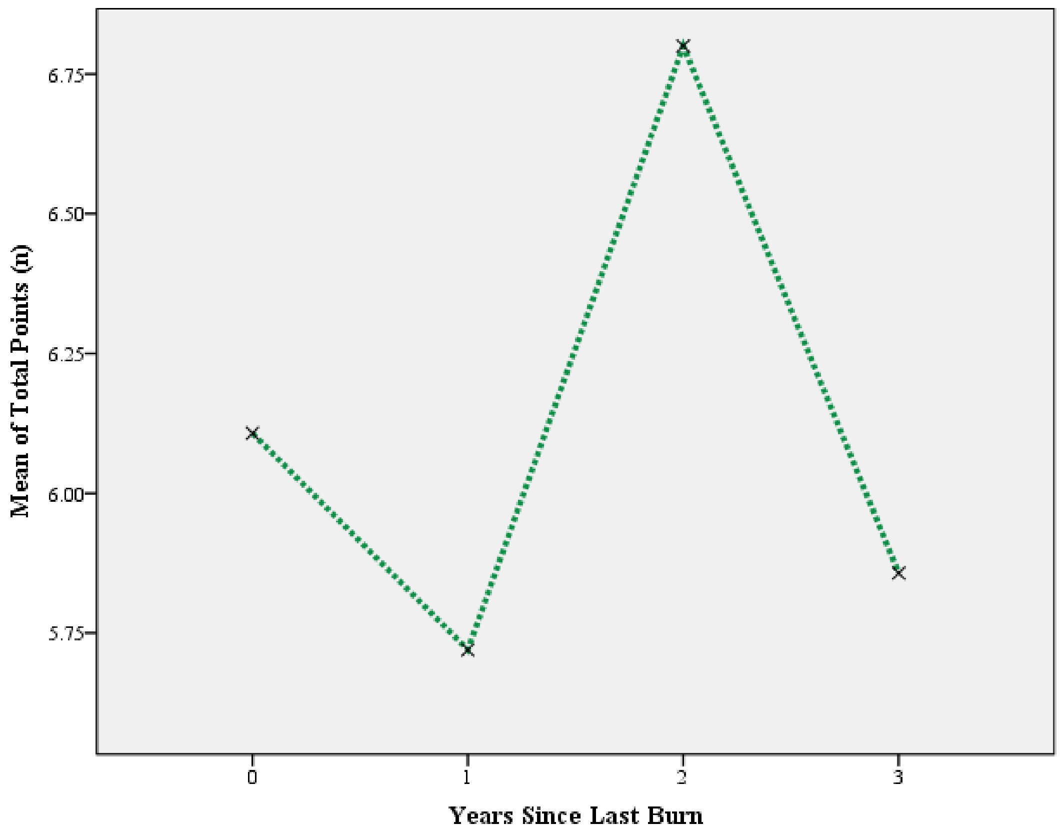

Figure 19. ANOVA results showing total antler points for male white-tailed deer 1.5 years or older with ≥ 1 point 0, 1, 2, and 3 years post-burn.

There were not significant differences in antler base measurements in relation to years since burn, however, post-hoc testing showed potential significance (F = 1.885, df = 3 and 171, p = 0.134). Ranging between 0 and 140 millimeters, there was not a statistically significant difference in antler base measurements between 0 years post-burn (mean = 61.7 mm) and 2 years post-burn (mean = 77.6 mm) (Figure 17). Post-hoc Tukey analysis *does* display potential significance and shows a mean difference of 15.88 mm in antler base size between 0 and 2 years since a prescribed burn.

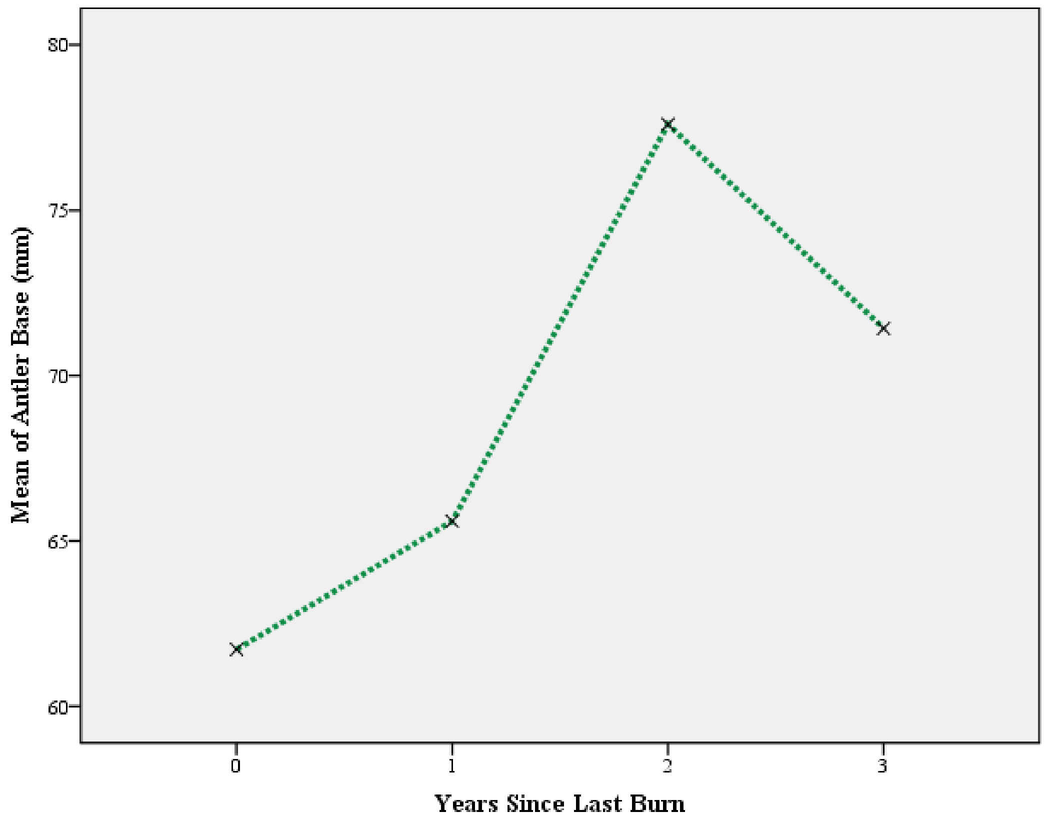

Figure 20. ANOVA results showing antler base measurements in millimeters for male white-tailed deer 1.5 years or older 0, 1, 2, and 3 years post-burn.

There were significant differences in antler beam measurements in relation to years since burn (F = 2.306, df = 3 and 171, p = 0.079, post-hoc p = 0.05). Ranging between 0 and 600 millimeters, there exists a statistically significant difference in antler beam measurements between 0 years post-burn (mean = 297.3 mm) and 2 years post-burn (mean = 388.0 mm), with a mean difference of 90.7 mm (Figure 18). Post-hoc Tukey analysis results show a mean difference in antler beam measurements of 90.7 mm between 0 and 2 years since a prescribed burn.

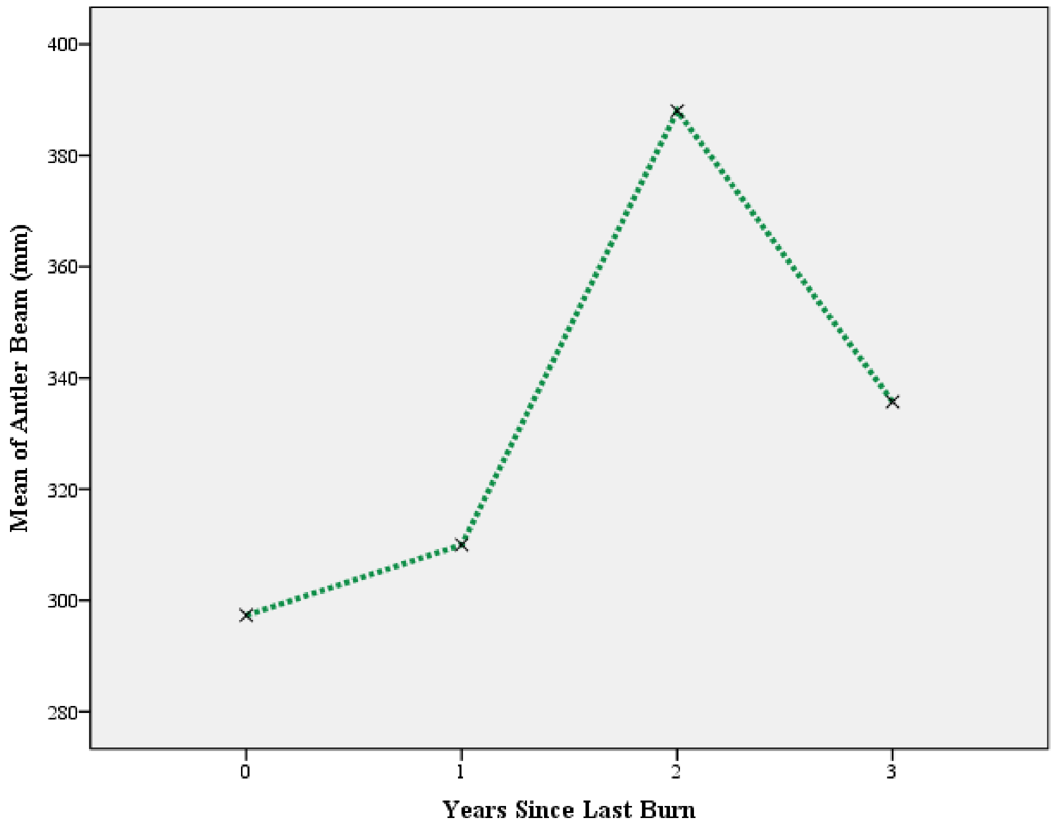

Figure 21. ANOVA results showing antler beam measurements in millimeters for male white-tailed deer 1.5 years or older 0, 1, 2, and 3 years post-burn.

There were also significant differences in antler inside spread measurements in relation to years since burn (*F* = 2.121, *df* = 3 and 169, *p* = 0.099, post-hoc *p* = 0.07). Ranging between 0 and 510 millimeters, there exists a statistically significant difference in antler inside spread measurements between 0 years post-burn (mean = 261.3 mm) and 2 years post-burn (mean = 300.0 mm), with a mean difference of 38.7 mm (Figure 19). Post-hoc Tukey analysis results showed a mean difference in antler inside spread measurements of 77.8 mm between 0 and 2 years since a prescribed fire.

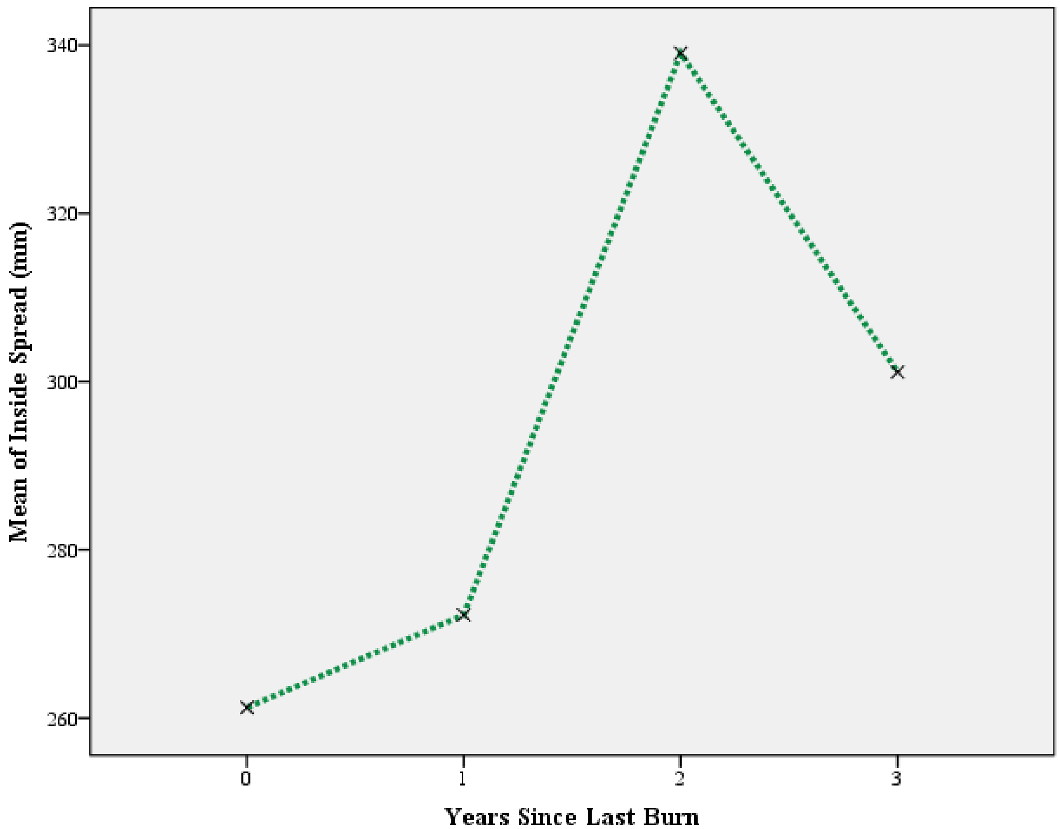

Figure 22. ANOVA results showing antler inside spread measurements in millimeters for male white-tailed deer 1.5 years or older 0, 1, 2, and 3 years post-burn.

DISCUSSION

In general, the positives of prescribed burning and other silvicultural activities outweigh the negatives. Impediments to effective ecosystem maintenance, improvement, and restoration due to potentially unrelated federal by-law limitations are unfortunate realities. Furthermore, risking the livelihood of future generations of endangered plant and animal populations because people are ‘not used to seeing smoke’ is subjectively ethically unjustifiable. There is not a single, simple ‘fix’ to any of these issues. Further research, public outreach, inter-agency cooperation, and governmental synergy with land managers and researchers is required in order to harmonize objectives and provide our nations flora and fauna with the necessary protocols, legislation, and public support for continued, healthy, ecosystem perpetuity.

Study Site Conditions and Management Implications

Most objectives were not met as defined and outlined by the USFS for their associated cover types. Future research, with an increased sample size should affirm conclusions. Secondly, the fire monitoring program initiated by the USFS and NFGT spans across multiple districts, data recorders, and for multiple years. There were occasionally minor discrepancies in the way the data were recorded due to the methodology being fine-tuned over time or by personnel recording the data in differing ways. Ensuring the data are recorded the same way across all districts will simplify future analysis. However, any discrepancies were minor, and the data analysis suggests there is a need to re-assess current practices and possibly even target objectives and goals. Lastly, the invasive Japanese climbing fern was noted in 9 of 24 plots (37.5%), which creates further implications and considerations when planning silvicultural activities.

By only using prescribed fire, the current fuel load objectives may not be realistic. Depending on what criteria the NFGT uses to define management objectives, there may be a need to re-visit the definitions and analyze if the goals are even realistically attainable. Ensuring the cover type objectives are not arbitrarily defined, but rather chosen due to historical accuracy, acceptable levels, or future desired conditions may help to more accurately characterize practical, attainable objectives. It appears that due to burn season, intensity, ignition pattern, overstory density, or any combination thereof, the current prescribed fire regime is not effective at reaching desired objectives.

The results support the idea of a multi-faceted and aggressive approach to silvicultural activities. The current ecosystem processes are not driven solely by one variable (i.e. prescribed burn years), but are in actuality an artifact of a combination of processes and variables. Obviously, fuels on the forest floor are contributed by the trees and vegetation associated with their systems. The purpose of the regression was to graphically illustrate modeled projections and to test how strongly related the ecosystem components are to each other. Since one of the most dominant and important considerations in current burn prescriptions is to reduce fuel loads in order to reduce wildfire chances and improve herbaceous growth, it is likewise important to note that fuels and litter depth were only moderately impacted by prescribed burns, but were strongly associated with overstory trees. A tiered approach to fuel reduction including the thinning of overstory and midstory tree densities in combination with prescribed fire may be a more effective approach to meeting fuel load objectives. This combination of thinning and burns may also help to provide more light to the understory layer to promote the production of native grasses and forbs, while reducing future accumulations of fuels and litter. In the case of fuel reduction, a winter fire in combination with three subsequent annual growing season/summer fires has shown to be highly effective (Trousdell, 1970).

In response to the current prescribed fire regimes, a mosaic of burn intervals and seasons may help push the targeted objectives in the desired direction. Most prescribed burns in these forests are conducted in the dormant season, although some compartments have been subject to growing season burns. Switching to growing season burns may help to stall or set back the encroachment of woody stems, which in turn can help promote the growth of native grasses and herbaceous plants. The results showed that an increase in woody stem densities exponentially decreased native herbaceous cover. The results also show a substantial increase in woody stems as years pass since the last prescribed burn, suggesting the importance of frequent fire.

Some literature suggests that biennial dormant season burning may help to decrease litter, sustain resource values, and promote herbaceous diversity (Brockway & Lewis 1996), but a switch to growing season burn cycles to more effectively reduce woody stems may be needed before such maintenance burns would be applicable. Carey (1993) suggests that the best method for attaining adequate hardwood reduction and improving the seedbed for future loblolly seedlings is a single strip fire during the summer. Additionally, if many of the problematic hardwood stems are exceeding ~2 inches (5 cm), summer fires have been shown to better reduce larger diameter stems (up to 2 inches or 10 cm) than winter prescribed burns (Wahlenberg, 1960).

Ensuring dedicated personnel are available in the summer months would be necessary in order to effectively meet growing season burn targets. In conversation with USFS employees, many fuel techs and fire personnel are out on detail fighting wildfires during peak historical burn season in East Texas (May). Without dedicated staff to ensure growing season burns are being officiated, summer prescribed fire goals would most certainly be hindered. Furthermore, incentivizing appropriate burn seasons and management practices may be necessary to meet targeted definitions and meaningful restoration instead of just meeting acreage-burns quotas. Multi-agency cooperation may also prove helpful during these months. Cooperating with state agencies such as TPWD or the Texas Forest Service during the growing season (if possible) might be a solution when USFS personnel are needed elsewhere on wildland firefighting details.

While fire and thinning helps to reduce the encroachment of woody stems that crowd, shade-out, and often outcompete native grasses, this combination may not be enough to realistically achieve targeted goals in heavily degraded and converted forests. Application of herbicide may provide the needed assistance in which to achieve impactful, meaningful restoration results and target objectives. Most likely, it will take a combination of seasonally changing mosaics of prescribed burns and burn years, thinning operations, ignition patterns, and herbicide applications to achieve desired results.

The long-term collection of fire monitoring data currently being executed by the Forest Service and NFGT is imperative to assess ecosystem changes over time. The current collection protocols do an excellent job at capturing a vast array of information from almost all levels of forest strata. This data will be vital in future research in order to continue to assess impacts and efficacy of management practices. Continued execution of this fire monitoring program in combination with adequately trained personnel following standardized recording methods is highly recommended. It may also be beneficial to designate certain compartments specifically for testing the effects of alternative burn prescriptions and trial practices.

Effects of Prescribed Burns on White-Tailed Deer and Management Implications

The white-tailed deer ANOVA analysis displayed interesting and important results. It is important to recognize the trend that all variables and measurements were greater 2-years post-burn than any other year. The analysis suggests that there is a direct link between deer body weight, antler size, and prescribed fire. The analysis provides evidence that objectively bigger, better deer can be found in a two year rough compared to 0, 1, and 3 years post-burn.

Harvested deer show improved body weight and antler size in environments two years since a burn with seemingly less hunters. It could be important to the public as well as agencies to recognize that the potential for improved hunting opportunities with a reduction in hunter-to-hunter competition can be found in areas 2 years post-burn. As the number of years post-burn increases, the number of harvested deer declines significantly. A multitude of reasons behind this may exist, but one hypothesis could be that the decrease in harvested deer can be attributed to the possibility that hunters are simply not hunting in thicker areas. As a personal observation, the forested ecosystems in east Texas become increasingly thick and difficult to traverse as years since the last burn increase.

Another explanation could be that deer in east Texas are displaying behavior traits explained by predation theory. A study done in the Rocky Mountains suggests that elk may limit occupation of areas with dense vegetation, as it is more difficult to see and escape from predators. The study showed increased elk activity in areas more recently burned (White, Feller, & Bayley 2003), and the lack of harvested deer in denser roughs in east Texas could potentially be explained by the phenomena shown in Rocky Mountain elk.

The nutritional quality and palatability of deer forage may be improved in 2-year roughs and recently burned areas. Literature on browse production and nutrient availability in relation to burn years shows an increase in deer browse production and quality after prescribed fires. Another explanation of these trends can be supported by a study that showed peak production of panicum, sedges, and forbs 2 years post-fire in combination with tree harvests and thins (Masters *et al.,* 1993).

It is important to note that many more variables need exploration and that future research is required between the white-tailed deer and prescribed fire relationship in order to draw more advanced conclusions and correlations. It would be advantageous to add browse surveys in order to identify vegetation status in varying years of rough to fill in some of the gaps and further explain what is happening in these areas ecologically. It would be interesting to add oxygen bomb calorimetry to browse surveys as to deduce the nutritional value and calorie content of preferred deer browse at varying stages post-burn. Future researchers might extend the “years since burn” and analyze what happens in roughs greater than 3 years, increase the sample size, and include population surveys in order to more accurately describe abundance of the deer populations.

Management objectives for white-tailed deer could include maintaining a mosaic of burn cycles on the landscape, ensuring appropriate rotations as to include hunter-friendly 2-year roughs alongside areas with a longer fire return interval in which to provide the deer with appropriate escape cover and potential safety zones in accordance to predator theory. According to the data, maintaining frequent burn intervals (1-3 years) could help to improve and maintain deer body weight and antler sizes, which in turn can improve hunter success and happiness, which carries its own set of economic incentives and implications for agencies, landowners, hunting leases, etc. Maintaining these frequent fire return intervals and burn rotations will also decrease woody stem encroachment, promote native grass growth, and help maintain ecosystems for other game species such as quail and turkey, as well as benefitting endangered species such as the red-cockaded woodpecker and Louisiana pine snake.

It may be valuable to the public as well as the agencies involved to add Boone and Crockett scoring to the harvested bucks at the check stations. The current data collection protocols only lack a few more measurements to complete the Boone and Crockett scoring method. Such measurements may help to illustrate easily comprehensible and universal average deer scores over time by district, and would give the public a standardized "analysis" in which to relate.

CONCLUSIONS

Generally, federal mandates and legislative actions have succeeded in their respective goals that have thus contributed to making the United States one of the most successful arbiters of ecology and conservation worldwide. However, some mandates and acts simply contain various side effects that could be addressed, or at the very least, recognized and worked around. The USFS and NFGT have been invaluable during this research, and are consistently seeking ways to improve and learn from field measurements, activities, and their associated analysis. Furthermore, this research was a relatively exploratory, short-range study. There are numerous variables, relationships, and limitations involved in ecosystem processes and management actions outside of prescribed burns.

The standardized methodology initiated by the USFS and NFGT to monitor long-term ecosystem changes and responses to prescribed fire regimes is an excellent strategy. An adopted and universally accepted guideline in which to record and analyze ecological processes is imperative to efficiently and precisely maximize management actions and restoration. However, the plot summary data displays a need to re-evaluate current management actions and burn prescriptions. If current practices are in actuality aligned with proposed goals, there may be a need to at least reassess the parameters as currently defined by the monitoring type descriptions and cover types. The need for future research is also imperative. An increased sample size by each monitoring type spanning for more years could provide much greater depth and conclusive results. However, the results of this study suggest a need to review current activities in order to maximize habitat restoration and maintenance henceforth.

USFS and NFGT recommendations include:

- Continuing the current long-term fire monitoring program and ensuring standardization of the recorded data among personnel.
- Re-evaluating the targeted goals defined by the geographic project units and monitoring types.
- Initiating a mosaic of varying fire return intervals, season of burns, and ignition patterns.
- Conduct thinning operations in areas with excessive tree densities in accordance with historical levels, and to aid in the reduction of accumulated fuel loads.
- Introduce herbicide applications where possible to help remove woody encroachment too stubborn for effective removal by prescribed fire.
- Re-introduce more prescribed burns during the growing season in accordance with historical timings.
- Incentivize and ensure dedicated personnel are present to perform growing season burns and increase multi-agency cooperation and teamwork.
- Designate some compartments as test areas in which to experiment with varying management actions to find optimal methods and results.
- Ensure prescribed fires are being conducted with the intent to meet designated objectives and habitat restoration goals and not to simply meet acreage quotas.

The results for the white-tailed deer analysis were consistent with previous studies in regards to potential browse abundance, vegetation quality, and prescribed burn years. The two-year peak is indicative of a beneficial relationship between white-tailed deer and frequent prescribed burns, most likely due to an increase in forage quality, abundance, and palatability. The results of this study are an important starting point for future data collection and research for white-tailed deer and prescribed fire in East Texas. Since experimentation into *direct* relationships between deer and prescribed fire is relatively novel, any recommendations are considered tentative due to the infancy of the project. However, outside of the call for future research, there are some provisional recommendations that can be made, based on the statistical analysis for maximizing deer body condition and hunter success while reducing hunter-to-hunter competition and hunting pressure on the deer population.

White-tailed deer and prescribed fire recommendations include:

- Creating a mosaic of alternating 2-year roughs and burn rotations in deer management areas.
- Continued promotion of prescribed burns as a beneficial management practice.
- Conducting periodic browse surveys to monitor vegetation and nutrient availability over time.
- Initiating the addition of variables to the deer check stations to complete the Boone & Crockett scoring method and subsequent dissemination of that information to the public as an outreach method.
- Trying to attain information about which national forest compartments deer are harvested in as to pinpoint deer locations to relate to associated burn years and fire return intervals.

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